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Estratégia de Conservação Integrada do Património Edificado

Integrated Conservation Strategy of Built Heritage

Universidade de Aveiro Departamento de Engenharia Civil
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Sistemas construtivos tradicionais e materiais naturais

Integrated Conservation Strategy of Built Heritage.

Traditional construction systems and natural materials

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Engenharia Civil, realizada sob a orientação científica do Doutor Aníbal Guimarães da Costa, Professor Catedrático do Departamento de Engenharia Civil da Universidade de Aveiro e coorientação do Doutor Humberto Salazar Amorim Varum, Professor Catedrático da Faculdade de Engenharia da Universidade do Porto.

Dedicatória

Aos meus filhos André Guilherme e Inês Sofia e a meus bisavós Olinda Cavadinha d’Almeida Magalhães e Leonardo Teixeira de Magalhães.

o júri

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palavras-chave

Conservação Integrada, Património edificado, Sistemas construtivos, Valor cultural, Estratégia, arquitetura de adobe, defeitos de construção .

resumo

O risco de perder sistemas de construtivos antigos é altamente relevante em toda a região do Mediterrâneo, mas também em muitos outros países do mundo. O Património de terra e os sistemas construtivos mistos com madeira estão a decrescer rapidamente e são alvo de propostas para integrarem listas de Risco pela UNESCO, ICOMOS e com alertas de vários investigadores de todo o mundo. Estes sistemas, representam um valor cultural das sociedades, que está a ser negligenciado devido ao desenvolvimento desequilibrado, às demolições, à falta de conhecimento, e à falta de diretrizes para a conservação, em vez de a expectável única razão, de deterioração devido aos agentes naturais ou ao seu próprio envelhecimento.

Embora algumas experiências de Conservação tenham sido bem sucedidas, os resultados ainda são escassos e os erros continuamente repetidos, impondo lacunas irreversíveis na leitura deste Património relevante, principalmente em áreas urbanas. Isto levanta questões sobre a abordagem à proteção, à conservação, e às razões que estão por trás de tão disseminada falha nos objetivos. A Arquitectura de Terra sofre precisamente destas dificuldades no estabelecimento de uma estratégia capaz de alcançar com sucesso o objetivo de preservar o seu Valor Cultural. O que requer uma investigação contínua e capacidade de comunicar a melhor estratégia de conservação capaz de alcançar com sucesso a compatibilização para a preservação do seu valor cultural, como apenas uma das etapas de um enquadramento equilibrado. Esta investigação tem como objetivo: descobrir as razões subjacentes ao fracasso de estratégias de conservação; investigar os sistemas de construção tradicionais, valorizando o caso da arquitetura de adobe; estudar a significância dos sistemas construtivos tradicionais como valores culturais a proteger e preservar; propor áreas de pesquisa de conservação dentro de um quadro de Conservação Integrada do Património construído, envolvendo o caso específico dos edifícios de adobe.

As primeiras análises mostram evidências de múltiplas causas de fracasso para o apoio de medidas de conservação. O que mais se destaca é a falta de uma estratégia integrada de longo prazo, num programa reconhecido e apoiado. Em segundo lugar, a continuidade das deficiências é expressa nas escolhas inadequadas em vários níveis da tomada de decisão, a ausência de medidas de manutenção e conservação. Em terceiro lugar, a falta de conhecimento sobre os sistemas construtivos tradicionais (de adobe), sua evolução e ampla interação com a arquitetura, a abordagem sobre compatibilização dos atuais padrões de conforto com o valor cultural, e, finalmente, o problema particular do corte hídrico e controlo da ação dos sais no edificado antigo, são causas de falha nas estratégias de conservação de adobe, por falta de informação e de investigação.

Esta pesquisa recomenda o reconhecimento do sistema construtivo como um valor cultural, para garantir a longevidade do Património construído tradicional, apoiado na investigação. Aborda as dificuldades de aplicação de estratégias de conservação, a nível internacional para melhor compreender as razões de sucesso ou fracasso. Propõe uma interpretação da evolução do sistema construtivo de adobe e identifica os principais defeitos, para apoiar a base de conhecimento de estratégias de conservação. Por fim, considerando o âmbito de uma Conservação Integrada recomenda uma abordagem que integre questões-chave de sensibilização para o património e investigação. O caso de estudo de construção de adobe enfatiza três destas áreas: a ligação entre a arquitetura vernacular e a arquitetura, para sensibilização do público; os problemas de compatibilidade com o conforto, para estratégia de proteção; e finalmente, o efeito da diatomite em barreiras de corte hídrico e aos sais, para apoio aos problemas técnicos de conservação do Património de Terra.

keywords Integrated Conservation, Built Heritage, Construction systems, Cultural Value, Strategy, Adobe construction system, construction defects, diatomite.

abstract

The risk of losing ancient construction systems is highly relevant in the whole Mediterranean region, but also in many other countries worldwide. The earthen heritage and the mixed construction systems with timber are decreasing very fast and being identified in lists of risk by UNESCO, ICOMOS and by many researchers all over the world. They represent a cultural value of the societies that is being neglected due to unbalanced development, demolitions, lack of knowledge, and guidelines for conservation, instead of the expected unique reason of decay due to natural agents or ageing. Although some conservation approaches have been successful, the results are still scarce and the mistakes continuously repeated imposing irreversible gaps in reading this relevant heritage, mainly in urban areas. This entails questions about the approach to protection, conservation, and the reasons behind such disseminated failure in these objectives. The earthen architecture shows precisely the difficulties in the establishment of a strategy able to successfully achieve the goal of preserving its cultural value. This needs continuous research and ability to communicate the best conservation strategy as just one of the steps of a balanced framework. This investigation aims to discover reasons for failure of conservation strategies involving the traditional construction systems, valuing the case of adobe architecture; to give significance to traditional construction systems as a cultural value to protect and preserve; to propose conservation research areas necessary in a framework of integrated conservation of built heritage, involving the specific case of adobe buildings.

The research methodology of this investigation is based mostly on qualitative methods and a case study about adobe construction system, its evolution since the 19th century until the middle of 20th century, and its interaction with architecture. The case study was used to address the main identified gaps of research needed to proceed with an integrated conservation and protection approach of adobe heritage in Portugal. A combination of sources was used following a multi-method approach: in situ surveys, collection of archive files (drawings, written documents and photos), published literature, published and unpublished reports from international organisations, photographic reports, open interviews, and laboratory tests.

The first analyses show evidence of multiple causes of failure for the support of conservation strategies. The most important is the lack of a long-term integrated strategy within a recognized and supported framework. Secondly, the continuity of shortcomings is expressed in inadequate choices at several levels of decision-making, absence of measures of maintenance and conservation. Thirdly, the lack of knowledge about the adobe traditional construction system, its evolution and wide interaction with architecture, the approach to the present standards of comfort, and finally, the problem of waterproof barrier and salt's effects are the main causes of failure in the promotion of adobe conservation strategies.

This research recommends the use of the construction system as a cultural value to guarantee the longevity of traditional building heritage, supported by research. It also stresses the importance of understanding the difficulties of application of conservation strategies, looking to a wider international area to better understand the reasons behind causes and eventual successes. It proposes an interpretation of evolution of the adobe construction system and identifies the main defects, both of which should constitute the base of knowledge of any conservation strategy. Finally, considering an integrated framework of conservation strategy, an approach is recommended that integrates key issues of awareness for heritage and research. The specific case study of adobe construction emphasized three main approach areas: the vernacular architecture for public awareness; thermal and comfort issues for protection strategy; and finally, the waterproof barrier with diatomaceous earth, its role in the decrease of salt's effects and as an effective barrier, for the use of research to solve technical problems of earthen construction.

LIST OF ACRONYMS

CRATerre-ENSAG	CRATerre – International Centre for Earthen Construction – Superior National School of Architecture in Grenoble (France)
DECivil-UA	Departamento de Engenharia Civil da Universidade de Aveiro (Portugal)
EAP	The World Heritage Programme on Earthen Architecture (UNESCO)
ESGallaecia	Escola Superior Gallaecia (Portugal)
FAUP	Faculdade de Arquitectura da Universidade do Porto (Portugal)
GCI	Getty Conservation Institute (USA)
ICCROM	International Centre for the Study of the Preservation and Restoration of Cultural Property (Italy)
ICOMOS	International Council on Monuments and Sites.
ICOMOS-ISCEAH	ICOMOS – International Scientifc Committee on Earthen Architectural Heritage.
SRU – Porto Vivo	Sociedade da Reabilitação Urbana – Porto Vivo
UA	Universidade de Aveiro
UNESCO	United Nations Educational, Scientific and Cultural Organization
VA	Vista Alegre Atlantis (factory and enterprise)
WHEAP	World Heritage Earthen Architecture Programme

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1. INTRODUCTION

1.1. The focus on protection of cultural value of traditional construction systems (adobe heritage) under an integrated conservation strategy

The construction system is a common base of work for architects, civil engineers and many other actors. For this reason, it is the “object” of shared decisions, and it can serve as a basis for achieving the main goals of protecting the cultural value of built heritage. This assumption is the foundation of this research. These shared roles should be consistent with the philosophy of action and with the main goals of protection and conservation. In this research, some of the international charters and concepts for debate are considered.

Cultural value, according to the Burra Charter, Australia, ICOMOS, is a complete concept involving aesthetic, historic, scientific, social or spiritual qualities seized by the past, present and future. Cultural value is expressed by the materiality of the subject as well as its structure, context, usage, meanings, and the places and objects associated with it (Lopes et al. 2014 pp479).

This consideration of cultural value as a broad meaning should be linked to the conservation philosophy; it works well to consider cultural values within an integrated conservation strategy because this strategy takes a transversal field approach under a multidisciplinary framework. Bernard Feilden in 1986 defined ”conservation” in a manner that still is very relevant and assertive: the dynamic management of change to reduce the rate of decay (Feilden B 2003). Cultural scientific, technical and natural heritage and resources must be considered to be authentic documents and valuable components. Interventions should be limited actions that are strictly necessary to ensure the continuing conservation of this heritage, but the technique and the materials used should not impede future reading, use or assessment.

As Feilden pointed out Conservation work is multi-disciplinary involving many skills that contribute to a balanced solution. The values of the built heritage should be assessed and put in an agreed order of priority, before the architect or other technician undertakes any project (Feilden B).

Conservation requires comprehensive socio-economic, legal and cultural planning that is integrated at all levels. Considering that intervention in traditional construction systems involves wider fields, it is important that the chosen framework combines interacting approaches.

In this sense, the concept of cultural value is addressed within the framework of an Integrated Conservation Strategy because all of the actors involved need to deeply understand their role in the process for its successful implementation. This means that the research is also able to identify the gaps, not only as a field for profit but also with the purpose of integrating the objectives in the field and the necessary outputs.

Thus, conservation should be prepared under a management plan that considers enhancing the significance of the built heritage; this plan should pro-actively assess, evaluate and finally plan the action. The Declaration of Amsterdam (1975) and the European Charter of the Architectural Heritage (1975) already addressed some terms used in Integrated Conservation. Nevertheless, this concept is also linked to Sustainable Integrated Conservation, which conceives of integration as involving cultural heritage in the planning and management of cities. However, in practice, cities and even city planning are not managed by politicians or technicians with a deep knowledge of cultural values or conservation; this concept of sustainable development frequently involves the use of cultural heritage as a resource to serve the interests of other areas. This is well expressed in some sustainable building concepts and revitalization of city centres, where in practice, the built heritage is often just a scenario or a brand mark for short-term strategies.

Considering some of the guidelines proposed by ICOMOS to preserve “objects” of significance, conservation management should involve the interaction of planning proactive conservation, promoting change and assessing impact. Although the term “change” can be a key point of error and the coverture to misunderstandings, if the starting point is the significance of the object, any action constitutes a change in relation to the present state and it is an opportunity to enhance the starting point. Nevertheless, the intent is that all of the actors use the same "language" and understand that the planning criteria should be subject to some conditions.

For this reason, this research considers that Integrated Conservation cannot be addressed by a single point of view but should be built upon an interdisciplinary framework that includes several levels of participation and that requires integrative systemic thinking as well as scheduled monitoring and evaluation mechanisms. A proactive attitude also defines integrated conservation, where all of the actors (entities or technicians or researchers or stakeholders, etc) present interdisciplinary actions for development. Therefore, the main requirements for achieving success are communication and integration. A further consideration includes recognizing and accepting all steps of the management plan presented in a preliminary approach.

1.2. An assessment of the failure of conservation strategies for built heritage

The scientific community in several countries has alerted us to the risk of disappearance for several construction systems, especially vernacular systems, recognizing their importance. This recognition that there is underlying cultural value to protect has been the subject of several communications, publications and guideline proposals by international organisations such as UNESCO, ICOMOS, ICCROM, The Getty Foundation, CRAterre, among others. Although, difficulty exists in relation to non-classified property as relief for humanity, their relevance to a country or to a region and the need for their effective protection should be emphasized. Therefore, it is desirable to address the factors cited within international documents about the causes leading to the risk classification of heritage.

Most of these reports identify causes behind the loss of cultural value; however, it is necessary to understand the importance of this loss for various societies. One line of analysis is to understand the basis of classification a Heritage at Risk. Balancing the understanding of the loss, it is important to realize whether the replacement will offer effective gains and whether its features will establish it as the heritage of the future. UNESCO and ICOMOS reports and researchers from various universities and organisations frequently warn about or address the risk of loss of heritage not associated with any specific continent or country. Hence, it is necessary to know the common factors underlying this risk. Can these factors serve as guidelines for diagnosis and proactive prevention efforts? Or are we seeing the irreversible course of development that is incompatible with Built Heritage protection?

The Convention Concerning the Protection of the World Cultural and Natural Heritage (Lopes et al 2014 pp164) identifies the main threats leading to inclusion of an asset on a risk list: a) disappearance due to accelerated degradation; a) projects of major public and private works; c) rapid urban development and tourism; d) destruction due to changes of use or of land ownership; e) deep changes due to an unknown cause; f) abandonment for any reason; g) armed conflict either ongoing or threatening; and h) calamities and disasters, major fires, earthquakes, land movements, volcanic eruptions, water level changes, floods and tsunamis. It is interesting to see that from 1972 to the present, the arguments remain valid for the characterization of a high number of situations. A second condition presented in the Convention established that World Heritage status can only be placed on a location with the consent of the member state. Therefore, without the proactive understanding of governments, the research, recognition and protection of assets may be reduced, despite the obvious recognition of jurisdiction. A special concern is due to some vernacular heritage that goes beyond borders and represents cultural links connecting Europe. This valuable multicultural heritage shares common characteristics between countries and can be lost due to a lack of coordination between governments. This is the case of adobe construction and mixed construction systems with timber and their link between Europe, Asia and America. This example of heritage is currently compromised due to the assumption that cultural islands are sufficient.

Five years after the convention, the Granada Charter (1977, pp228-9) presented a new topic: the protection of rural architecture. A list of the main problems was noted: the mischaracterization of the environment due to the industrial development of agriculture and the rural exodus. Within this last point, two factors are mentioned that are still present in the collected data: a) the appropriation of abandoned buildings by a city population, which are then mischaracterised through changes to their character (including several cases of demolitions), and b) the proliferation of new buildings, used as a first or second residence, designed ignoring tradition. The Charter continues, stressing that these phenomena contribute to the demise of the local culture subdued to the dominant culture in our industrial society, and the impoverishment of the cultural heritage. It is in this context that some farmers alter or destroy their homes to replace them with urban models. In addition, poorly designed industrial buildings can also profoundly change the character of the landscape.

Finally, a disproportionate promotion of tourism causes profound disturbances in rural life and a general degradation of the local environment. Tourism, which is usually assumed to be an opportunity, can also cause a loss of the integrity of built heritage.

Although these documents are more than 30 years old, the risks threatening the loss of heritage remain real in many countries.

Reviewing the body of literature addressing the physical state of traditional built heritage, it was noticed that most adobe regions lack a conservation policy and preventive measures. Although this situation is not exclusive to adobe construction, a particular threat is seen emerging, or are without conservation measures and maintenance. Correia M and Fernandes M (2006) maintain that particular difficulties affect the efforts to conserve and the efforts to prevent decay. The examples of attempted preservation through maintenance or conservation manuals (Achenza M 2008) (Tavares A et al. 2014) are still very recent and have not been disseminated in the Mediterranean region or in other regions of the world. Nevertheless, these offer fundamental support for methods of conservation and the prevention of poor practices.

The lack of proper action by national heritage organisations or governments is a key issue in the loss of this building heritage. Additionally, due to problems in tax criteria and the lack of governmental measures to promote conservation and rehabilitation, the owners of adobe buildings are proposing that their own properties be demolished. These issues were observed during this research when accompanying the municipal technical staff on inspection visits to these buildings. In fact, the lack of an accepted platform involving wide interests—the owners, the municipality, the financial authority and the government—explains this strategic failure.

In addition, a lack of information concerning (i) the criteria for promoting the cultural value of this heritage; (ii) less intrusive methods of conservation; and (iii) the inadequate practices presently established, including incompatible materials and techniques (for example, the use of cement plaster to repair coating detachment) are just a few examples of the lack of research or of good communication between research and practitioners that compromises an adequate conservation strategy.

Furthermore, the literature also refers to the use of a more sustainable approach to the conservation of earthen heritage (adobe built heritage). Nevertheless, the term ‘sustainability’ then introduces highly intrusive approaches in the name of energy efficiency and comfort. This is evident when the criteria used in rehabilitation interventions are observed, including the philosophy of the totally new inside an ancient box. Again, this philosophy is particularly negative because it is based on the research field supporting the massive destruction of integrity. The lack of awareness of this problem on the part of the research field and communication problems between research and technicians must be taken into account during the strategic planning of an integrated conservation approach. Other levels of compatibility also present difficulties. With the advance of research, conservators realized that using materials different from the original fabric in earthen heritage conservation practice could create new causes for failure in the medium and long term. Nevertheless, research about materials still presents many challenges, even in terms of durability and proper ageing process.

1.3. The research purpose

A review of international publications addressing the conservation of adobe architectureFigure 1-1 – European map identifying earthen construction (adobe is the brown strong color) in Terra Incognita, 2008) (Figure 1-1) in the last 15 years reveals a strong attempt to present case study papers and the results of research. The literature reveals that several areas have been widely researched, particularly the identification and characterization of analytical methods as well as material improvement and performance (Kanan, 1995); structural performance (Costa A et al 2007, 2014) (Varum H et al. 2006) (Lourenço, 2006); historical study of earthen construction structures (Isik B, 2006) (Jaquin, 2008) (Tavares A et al. 2013); physical condition (Matero, 1999 and 2003) (Guillaud et al., 2008); traditional methods and materials (Licciardi, 2007), architectural design and typologies (Tavares A et al., 2009, 2010, 2011, 2012, 2013, 2014) (Guillaud et al. 2008) (Fernandes M, 2014), protection and management of sites and monuments (Crosby et al., 1992) (Costa A et al 2014), (Cooke, 2003); seismic retroffiting (Cancino and Matero, 2003) (Vargas et al., 2009) (Costa et al 2007, 2008) (Varum et al 2006), (Blondet M 2007); conservation intervention case studies (Aguilar and Falck, 1993) (Cooke, 2004); building materials and techniques (Costa A, 2000) (Correia, 2007) (Viñuales, 2007); plaster analysis and preservation (Matero, 1999, 2000) (Faria Rodrigues, 2005) (Velosa A et al. 2007).

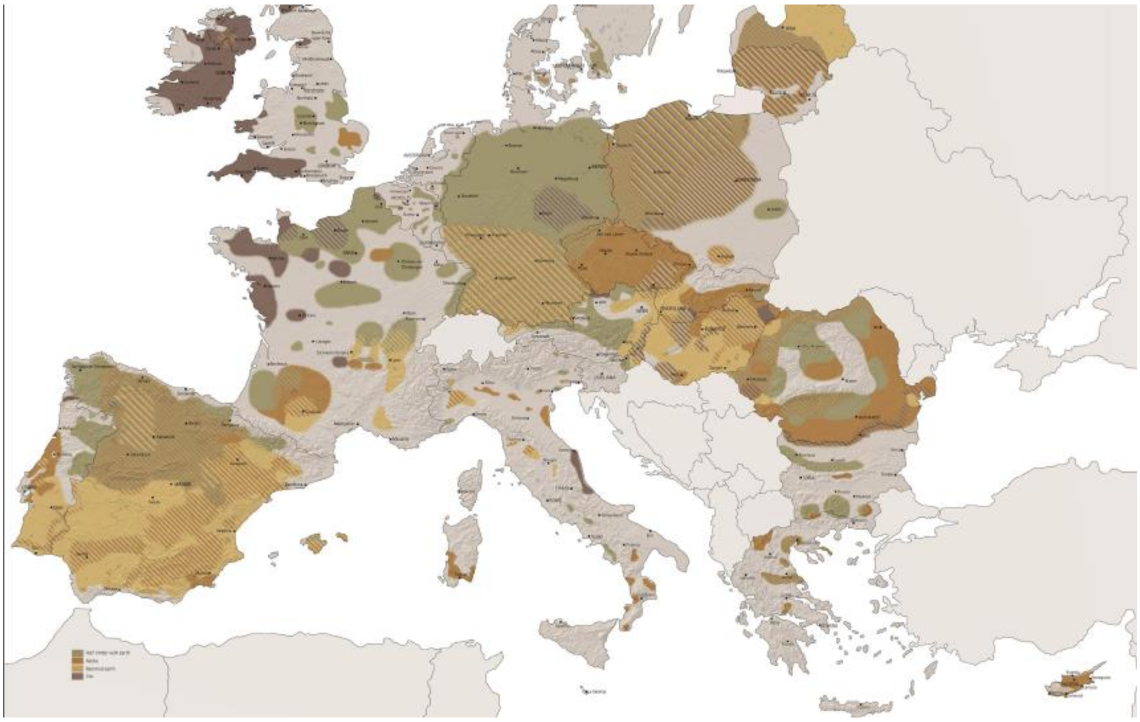

Figure 1-1 – European map identifying earthen construction (adobe is the brown strong color) in Terra Incognita, 2008)

A study of the literature makes evident a general tendency to consider each case study as an isolated matter, without learning from the experience of others. In addition, when analysing adobe architecture conservation procedures, there is a tendency to repeat mistakes at different stages of intervention, including in the initial strategy framework. This tendency may be due to the lack of concerted strategies between all of the actors and recognition of their contribution to the methodological approach; the lack of a conservation programme or plan and its effective implementation; the lack of conservation guidelines and legislation specific to adobe construction and the lack of national conservation regulations in general; the lack of knowledge of local conditions; or the lack of identified roles and responsibilities in the process of conserving and elaborating conservation plans. However, in general, there is a lack of thorough reflection on the problem of the conservation framework in earthen architecture and, consequently, in adobe architecture. The present research focuses mostly on structural assessment, structural performance, material analyses, construction technology, conservation materials and rehabilitation issues. There is a lack of literature or research that addresses the conservation process using a theoretical approach and a conservation strategies framework compatible with maintenance of cultural values. Again, there are very few manuscripts or book chapters that provide analysis of conservation theory in adobe architecture, considering the construction system as a cultural value to be preserved (Warren, 1999) (Correia and Fernandes, 2006) (Tavares A et al 2012). The literature is also restricted in the assessment of conservation frameworks and in cross evaluation of the distinct methodological components. The few existing assessments covering earthen heritage conservation are addressed in the some parts of international conference proceedings, in their post-proceedings (Terra 2000), or recommendations (Terra 93, 1993) (Terra 2000) (Terra 2012) or in the few literature reviews about the field. Moreover, for other materials such as stone or timber, the literature has led to international consensus on preserving authenticity. On the contrary, adobe built heritage presents a very recent approach offering a comprehensive conservation process to guarantee the preservation of its authenticity (Tavares A et al., 2012).

It is therefore necessary to consistently assess and review the literature in vernacular heritage conservation, but especially the response to the prominent hiatus between conservation intervention addressing failure and the lack of cultural sustainability topics. The purpose of this research is therefore as follows:

- Identify the reasons for failure related to the conservation framework strategy for traditional architectural heritage with a special focus on adobe built heritage;

- Give significance to the preservation theory of traditional construction systems and provide knowledge about traditional construction systems (mainly adobe) to serve as a basis for protecting its cultural value;

- Provide knowledge about the defects and vulnerabilities of adobe construction systems;

- Provide specific examples of original research that comply with some of the sectors of the framework conservation strategy and with cultural sustainability; emphasize knowledge regarding the interaction between vernacular built and architecture; thermal comfort and the need to surpass “rehabilitation” contradictions; and waterproofing barriers with diatomaceous earth and their impact on the reduction of a rising damp front and the effects of salts.

The following sections explain the research objectives of this investigation.

1.4. Research objectives of the investigation

It is commonly believed that natural agents are the overall cause for damage to traditionally built heritage. However, when thoroughly evaluating the reasons for the failure of conservation strategies, several areas included in these strategies have not been accomplished. This has a major impact on the protection of traditional built heritage because its cultural value involves the basic preservation of the construction system. From the literature review, problems in the lines of approach were noted, including insufficient investigation into communication problems between research and the technical field. This leads to the absence of correct conservation frameworks based on proactive and preventive measures; these cannot wait for the final results of research. Further, gaps in the fields of compatible materials and compatible techniques are leading to very intrusive actions for the built heritage. Again, this intrusion involves a lack of a broad concept for the conservation strategy that integrates as a major objective the protection of the cultural value of the construction system (which is more vulnerable in the case of traditional construction). This integration would entail questions concerning the conservation approach, differences between conservation strategies and the reality in the field, and also reasons why mistakes are repeated and why there is a continuous loss of traditional built heritage, namely, adobe heritage. For this reason, it is necessary to identify and understand the causes behind the failure to protect cultural value, the causes of damage and the research gaps in the framework of an integrated conservation approach. Answering these questions can help identify suitable methods to reduce the damage imposed on this built heritage and improve upon the current situation of neglect. Therefore, the main research objectives are:

- To identify the reasons for failure in traditional heritage conservation (focusing on the specific case of adobe heritage).

After the diagnosis of causes of failure, it is important to recognize criteria for intervention in terms of a strategy framework and the role of research in supporting the conservation practice. Consequently, the second research objective is:

- To give significance to the cultural value of the construction system as a common base for architecture and engineering as well as for its role as the basis of traditional heritage protection; to enhance multicultural values and to use them as a basis for influence, offering a motif for promoting traditional adobe heritage.

In the literature review, when establishing a conceptual approach to traditional built heritage, a common gap identified was the lack of an accepted theoretical framework. There was also inconsistency between conservation theory and practice for this type of heritage. Furthermore, defining strategies will clearly benefit the protection and preservation of this heritage. Thus, a third objective of this research is:

- To analyse international difficulties and best practices for conservation strategy frameworks, which can provide a broad assessment of the research gaps to support more effective planning and practice.

During the preparation of in situ surveys while establishing the research needs to fill the identified gaps under a framework of an integrated conservation strategy, three main areas were chosen to assess and to develop as future research. As a result, the fourth and last objective of this research becomes essential:

- To provide examples of research gaps to fill and to present preliminary relevant results of research to use in three different levels of an integrated conservation strategy (cultural value enhancement; compatibility between cultural value protection and thermal comfort; ancient solutions for waterproof barriers for use in the debate regarding new solutions).

A reliable methodical approach of integrated conservation was developed through the investigation. The research framework was created to accurately correspond to the research objectives, which in turn correspond with the chapter topics. Chapter one relates to research objective of conservation framework; Chapter two addresses the research objective of main characterization, strategies and the main objective of conservation strategy failure; Chapter three explores the research objective of characterizing the adobe construction system; Chapter four reviews the research objective of defects and historical seismic event; Chapter five presents the findings and challenges to the research. Furthermore, key issues were addressed at the end of these chapters.

This systematic approach provides consistency to the overall thesis under an integrated conservation approach and supports the achievement of the research objectives, which represent the basis of the strategy framework that guides this study. This research is a critical investigation of the current situation in the protection of a traditional construction system (namely, adobe heritage) as a cultural value. The general purpose of this study is to identify the international critical factors present in conservation strategies and to contribute to filling a gap in the current knowledge, concerning a multidisciplinary engagement.

The research findings will contribute, in particular, to improve conservation knowledge of adobe heritage and, in general, to enhance conservation framework strategies and adobe heritage protection.

1.5. Research methods and approach

The research methodology of this investigation is based on a case study strategy using mostly qualitative methods with the exception of the last topic of research, waterproof barriers and salts effects, for which quantitative methods were applied. Each case study had specific objectives to show the role of research in the framework of an integrated conservation strategy. To obtain an adequate extent and variety of data, a combination of sources was used for data collection following a multi-method approach: in situ surveys, the collection of archive files (drawings, written documents and photos), published literature, published and unpublished reports from international organisations, photographic reports, open interviews, and laboratory tests.

The data were collected in situ mainly in the Aveiro district (Portugal) as well as from national and international sites and institutions or from organisational archives. The survey approach provided an overview of the present reality in the field of civil architecture conservation. The visits to international sites were crucial for allowing a proper evaluation of the comparative data. Other important written resources were the national and international reports addressing conservation strategies and evaluating the state of conservation of built heritage. Finally, interviews conducted during the site visit to complement the data gave important clues for understanding the use of these spaces in the past and the public's expectations in relation to urban conservation. The integrated approach made it possible to correlate results from case studies with expert perspectives, encompassing the framework of failure, strategies, planning systems, intervention methodologies, conservation practice strategies, criteria for intervention, and the significance of conservation theory.

Due to a lack of documentary sources linked to the methods of construction in the region previous to these centuries, the building stock of the 18th-century and the scarce previous examples are the main source of information for those periods, and as such, they are highly relevant for understanding the process of evolution.

All of the roof trusses in this study belong to buildings over 75 years old that were identified as relevant for the characterization of architectural design in the transition phase between traditional construction and the application of reinforced concrete. The case studies belong mostly to the northern and central region of Portugal, mainly to the Porto (Porto is classified by UNESCO as a World Heritage Site) and Aveiro districts (relevant due to its landscape and its earthen architecture).

This study is based on the information from architectural processes in the Archive of Porto and architectural processes in the Archives of Aveiro region. In relation to this database, some decisions made during the selection of data should be clarified: i) the main criteria for choosing processes from the Archive of Porto were the specie of timber used specifically for the roof/floor structures because that identification is scarce in the Aveiro Archive. For this reason, processes that identified a generic construction materials or components used in the construction were not considered; the main criteria for the selection of the processes at Aveiro Archive was the existence of an architectural design and written documents, to provide a basis of comparison with the more complete design processes of Porto. The observations in situ were fundamental for cross referencing the information from the archives with the existent building stock, which also clarifies the types of solutions used during periods with less information.

1.6. Thesis outline

This thesis is organized in six chapters. The introductory chapter explains the gap in knowledge and formulates the research objectives to fill this gap. This chapter defines the conceptual framework of the investigation. Chapter two addresses the importance of traditional construction systems as cultural values to be protected. To better understand the reasons behind the difficulties in achieving this goal, the international proposals for construction systems at risk and the main vulnerabilities identified in reports were analysed. This chapter includes manuscript that was published in Tavares A et al. (2013a). Chapter three investigates the characterization of the adobe construction system through the first case study and addresses its links of influence with other regions, its evolution, the role of technicians and socio-economic change and finally its interaction with architecture. Resuls and findings of this chapter include manuscripts that were published in Tavares A et al. (2011a; 2011b; 2012a; 2012b; 2012c; 2013a; 2013b 2014b). Chapter four analyses the main defects of the adobe construction system and its vulnerabilities and the incorrect interventions by technicians; finally, it addresses the importance of understanding the impact of a seismic event on the built heritage through the case of the 1755 earthquake and its impact in the Aveiro region. Resuls and findings of this chapter include manuscripts that were published in Tavares A et al. (2011a; 2012a; 2012b; 2012c; 2013a; 2014a; 2014b). Chapter five presents the research findings in terms of objective 1 (criteria for an integrated conservation strategy), objective 2 (the significance of protecting a cultural value through the last built heritage of contemporary adobe with modernism), objective 3 (key reasons for pre-evaluating thermal topics versus the preservation of cultural value and the results of research addressing a major technical problem – the waterproof barrier with cement, air lime or hydraulic lime in addition to each type of solution, mortar or diatomaceous earth, including their impact on the progression of capillary and salts). Resuls and findings of this chapter include manuscripts that were published in Tavares A et al. (2015) and in Mendes C et al. (2015). Finally, chapter six presents the overall conclusions of the thesis and future work.

2. CONSTRUCTION SYSTEMS AT RISK

2.1. Introduction

This chapter includes the manuscript published by the author (Tavares A et al. 2013a) and research on the international classification of built heritage at risk.

It addresses the concept of a construction system and a classification of its types according to its industrialised features. This explains why traditional construction systems should be inserted in specific frameworks compared with the current industrialised concept.

This research emphasises some of the main aspects from the ancient treatises and books that discuss adequate structural function of construction systems. All aspects involve the foundations, walls, openings, corners and roof in terms of the analyses of adobe construction and mixed systems with timber. Although the thesis developed a case study research that is primarily based on adobe architecture, it also focuses on mixed systems with timber. Due to their high multicultural value, construction systems that broke the barriers of the continents present interesting variations to their adaption to seismic prone regions. Improvements in the configuration of a construction system to achieve satisfactory performance in these situations should be emphasised. Several links exist among different constructions systems, such as *baraccata* or *gaiola*. This study only emphasises one system—the issue of the connections in the corners. The awareness of the common links among construction systems is a critical issue for their safeguard, as they can represent a common history. The lack of awareness of the importance of these cultural values for societies causes the risk of loss of built heritage. This chapter addresses the main areas that are at risk and encounters the same types of threats as adobe-built heritage based on international documents. The preservation of the cultural value is presented in this study as the mainstream support of the integrated conservation and is also addressed in this chapter.

The dichotomy— urban development and conservation of the built heritage—enables reflection on the maturity of societies in relation to the value of its history in the present and its projected future. This issue presents a difficult debate that is dependent on the civic participation of duly-elected leaders who understand that a greater amount of knowledge will produce the least amount of error in the final decision.

2.2. Definition of a Construction System

The evolution of a construction system over the centuries is the result of a process of adaptation to climate, geographical location and soil conditions. It is also influenced by past and present cultural backgrounds, economic considerations, tastes and fashions. However, the progressive industrialisation of methods of construction and the increasing number of requirements from society for quality control and assurance in construction practices and building codes has fostered increased control over the characteristics of materials and components and structural and environmental building performance. The concept of a construction system has gradually become closely linked to the definition of an industrial process, as demonstrated by the following set of statements, which encompasses the past 40 years. A construction system is defined as follows:

- a "combination of structures involving organisation, technology and design processes";
- a "combination of production technologies, component design and construction organisation";
- a concept that "must only be applied to identify advanced industrialised processes of construction, which can be divided into three categories: i) the design process and the management and control of construction methods; ii) technical subsystems such as the structure, roof, and walls; and iii) the complete range of activities in the production, construction and maintenance of all specific components";
- a concept that "encompasses the activities that are required to build and validate a new system to the point that it can be submitted for acceptance. This presumes an emphasis on the design process to ensure that technical solutions are based on the functional and operational requirements captured during the analysis phase, which includes a series of tests of each component to verify the entire system".

These definitions reveal the underlying assumption that a construction can be considered a system if the foreseen performance of each of its materials and components follows a continuous process of appraisal and control from the planning phase to the design and construction phases and eventually its use.

As noted by the Sebestyén statement (Sebestyén G 1980), difficulties may arise when these definitions are applied to pre-industrial or vernacular architecture. The production processes that involve these construction systems were conditioned by diverse social structures and cultural backgrounds. In many regions of Europe, the production of construction into the 20th century was based on the organisation, delivery and application of different crafts within the building site-crafts learned by apprenticeship and oral communication in which quality control was conspicuously dependent on the pride, skill and sense of ownership of the process by the craftsmen. This process entailed the repeated application of the “rules of thumbs” and procedures with well-established performance and experienced relatively modest variations and improvements for adaption to different environmental and economic conditions and client demands.

Due to the differences in the mode of production of traditional versus industrialised construction, the requirement that both classes of buildings are expected to fulfil can be identical, as formally expressed by Vitruvius: environmental comfort, aesthetic comfort, and durability via robustness. By definition, any system consists of different components with different shapes, functions, materials and crafting. For their optimal performance, the quality of all materials, their compatibility and the correct design and dimensioning for each component should be guaranteed to fulfil its function and the correct type of connections between elements and components to ensure that the entire system functions.

The connectivity between the elements and the components that fulfil different functions is a critical aspect for the ability of the system to withstand the actions with which a building is designed and for its resilience against unforeseen environmental demands. This connectivity can be identified as follows:

- the foundations and their relation with the characteristics of the soil;
- the connection between the footing and its upper structure, including waterproof layers;
- the connection between vertical elements;
- the connection between vertical and horizontal elements;
- the connection between vertical elements and the roof; and the connection and correct position of nonstructural elements, such as chimneys, balconies, windows, doors and other elements, with respect to the total layout and position of the structural elements.

These concepts have been codified in the Western world (Vitruvius, *De architectura libri decem* (McEwen I 2003; Rowland I 1999) since Roman times and since a similar time in the Asian world (although Yangzi Fashi, which is the earliest surviving treatise of Chinese architecture, was written by Li Jie during the mid-Song dynasty from 1097-1100, it is a re-visitation of older pre-existing texts [Guo Q 1998]) and represent the basis of any acceptable construction, regardless of whether the construction comprises vernacular or formal architecture. To accomplish the Vitruvian "firmitas", knowledge of the mechanical behaviours of materials and components and their expected performance, as opposed to their achievable performance, is essential. For traditional construction, this knowledge was empirically developed via the act of construction. It constituted a system of knowledge to be applied to a complex system. Although a minority of sources have documented the process of knowledge transmission in the pre-industrial construction yard (one for all Villard de Honnecurt), additional information about the development of structural resilience against seismic action in historical construction and its dissemination throughout time and different regions can be obtained by a comparative reading of historic architectural treatises, as outlined in the next section.

2.3. Main Construction Systems

Construction systems may be grouped into traditional and industrial systems according to their conception and considering that each system has associated and specific approaches to durability and safety. In addition to these two groups, composite construction systems were employed in certain periods as a consequence of architectural demands or as a simple evolution of traditional methods to introduce new materials. In this chapter, a division of the construction systems into three main groups is proposed to highlight other aspects in addition to structural systems.

Construction systems can be organised into three main groups according to the origin of the materials, namely, if the materials are raw materials or industrially processed materials:

Group A – primarily composed of natural raw materials;

Group B – primarily composed of industrial materials;

Group C – a combination of natural and industrial materials in different construction parts or components.

Group A is primarily composed of traditional construction systems, such as earth construction solutions (adobe, rammed earth, and cob), timber structural systems, composite systems that are composed of masonry and timber (half-timbered, *hımış*, *bağdadi*, *quincha*, *taquezal*, *bahareque*, *dhajji dewari*, *pontelarisma*, *pombalino*, *baraccata*, among others), stone masonry and non industrial brick masonry structural systems.

Group B is defined by modern engineered systems, such as systems that involve reinforced concrete (RC) or steel structures or industrial brick masonry. From this group, only the reinforced concrete structures will be discussed in this book. Buildings that belong to the Modern Architectural Movement or Modernism, which existed until the 1950s, are examples of the application of RC structures.

Group C is defined by traditional construction materials and systems that are combined with engineered solutions. Many of these solutions were adopted for residential buildings after World War I, particularly until the 1940s. In some European regions, composite systems with reinforced concrete elements were employed (Tavares A et al. 2012a, 2013b); some of these systems belonged to the first stage of the Modernism architectural movement. Some of the structural recommendations/solutions for seismic regions that are presented in building codes include the use of composite systems with RC. The use of RC ring beams in loadbearing masonry wall structures of adobe or rammed earth at the level of their foundations and openings is an example of this situation. The Turkish Building Regulations (1998) refer to this procedure: masonry foundations should be built with reinforced concrete footings and lintels (Akan A 2004). The use of reinforced concrete elements in adobe construction was also applied by Peruvian rural community housing after the 2001 earthquake in Moquegua (PREDES 2001). The use of ring beams, lintels or thin slabs of reinforced concrete in adobe construction was common in the 1930s in Portugal (Tavares A et al. 2011a, 2012a); however, they were very thin and were not intended as a measure to improve the seismic behaviours of structures.

2.3.1. Group A

Group A includes the most important expression of ancient construction systems, which may soon disappear in several regions of the world, such as in timber buildings in Turkey, which is mentioned in UNESCO reports, and the extensive range of earth architecture throughout

Europe, as mentioned by several researchers involved in the Terra Europae project (2011). This chapter includes some earthen construction types due to the increased interest in the preservation of these structures considering their cultural value. The restoration of earthen buildings is being subsidised by governmental rehabilitation schemes or other institutional financial support, such as the schemes in Cyprus (Llamps R et al. 2011) and Sardinia, in a limited number of cases. In addition, this activity has increased in some countries, such as Austria, Germany (Vegas F et al. 2011), Australia and the USA, due to the interest in the use of these materials for new architectural proposals, which can also be a method for changing mentalities and promoting the desired protection of this heritage.

An extensive variety of methods of earth construction and many researchers have noted the existence of earth buildings in almost all continents since the Neolithic age. Their presence in Europe has been recorded, for example, via the remains of the Etruscan civilisation dating to the 7th and 6th centuries, B.C. (Dipasquale L & Mecca S 2011). In Germany, earthen buildings exhibited a similar form to wattle and daub buildings from approximately 4000 B.C. (Guérin R et al. 2011); in Aegean areas (Bulgaria, Greece, Cyprus and Malta) and Italy, construction styles exhibited minimal change since the Neolithic era, which is a phenomenon that was also observed in parts of northwest and southeast Europe (Chabenat M et al. 2011). In Cyprus, earth constructions existed as early as 9000 B.C (Mecca S & Dipasquale L 2011). During the Roman Empire, earth construction techniques, such as adobe masonry, were employed in southeast and east central Europe (Mecca S & Dipasquale L 2011; Vegas F et al. 2011). The colonisation of the Eastern Mediterranean by the Romans and the arrival of Muslims in some regions are considered to be some of the forces that caused the dissemination of earth construction techniques (Ribeiro O 1969). Some remaining evidence of this process is rammed earth in France (Poitiers) and military fortifications that were constructed with rammed earth in Portugal (Correia M et al. 2011).
Currently, earth constructions exist in many European countries; the majority of these constructions are derived from the first half of the 20th century. However, buildings from the 18th and 19th centuries exist in Greece, Portugal, Italy, Cyprus, Denmark and many other countries, as noted by the Terra Europae project (2011).
A minimum of twelve main techniques of construction using earth have been identified by Houben and Guillaud (1994). The earthen construction systems identified represent some of the most widespread techniques, include rammed earth (monolithic) Figure 2-2, adobe

(masonry) Figure 2-3, Figure 2-4 as shown in and *tabique* (loadbearing structures) Figure 2-5.

Similar to other systems, the evolution of the earth construction system was dependent on the awareness and understanding of methods to improve the system.

Figure 2-2 - Rammed earth construction, Portugal [credit Humberto Varum].

Figure 2-3 - Adobe production, India [credit Aníbal Costa]

Figure 2-4 - Adobe construction in Portugal [credits Alice Tavares]

Figure 2-5 - Traditional *tabique* construction in Portugal [credits Alice Tavares]

In earth construction, the foundations in some of the variations, including the use of stone to achieve more efficient resistance to the effect of water, such as rain and capillary rise in saturated soil. A concern of ancient treatises, which also proposed foundations with stakes and directed the most durable timber species for use on the most vulnerable situations, such as silt soils. In regions with a low availability of stone, brick was sometimes mixed with stone masonry regarding the same objective. This solution is visible in the Mediterranean regions and Greece, where the foundation extends from a height of 0.40 m to a height of 1.20 m (Bei G 2011), or in Portugal (Tavares A et al. 2010a) and Cyprus until the 1950s (Llamps R et al. 2011). It also exists in Turkey and Macedonia (Karydis N 2003; Zeren M T et al. 2011). This characteristic was linked to the desire to improve the building's durability, i.e., to isolate the timber structure and the adobe masonry from direct contact with the ground, which not only improves the resistance to decay due to moisture but also prevents termite attacks in hot climates.

In some regions, such as the Central region of Portugal or Istanbul (Turkey), adobe constructions included a ventilation space between the ground floor level and the soil level, with holes in the foundation walls to enable air circulation (Figure 2-6, Figure 2-7). This space improved the conservation of the timber and permanent drying of the wall base (Tavares A et al. 2010a). As mentioned in Alberti's treatise, this issue is an important aspect that can also be observed in old stone masonry constructions. Another example is noted by Sahin in relation to the base of traditional buildings in Turkey: a timber beam is placed on a stone platform inside the foundation walls and joists are placed on this beam. Between the stone platform and the pressed earth, is an air space for ventilation, which ranges from 0.20 - 0.30 m. From the end of the 19th century to the mid-20th century, the ventilation space (Sahin N 1995) in constructions in the central region of Portugal (Figure 2-6), usually consisted of more than 0.50 m (Figure 2-7).

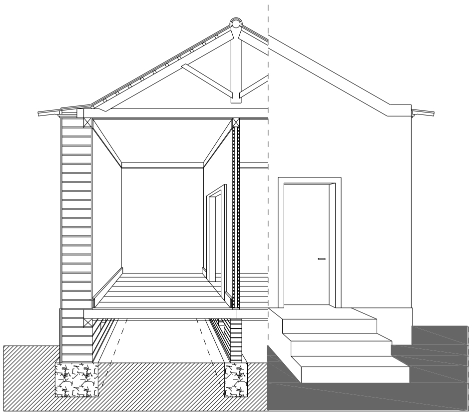

Figure 2-6 - Scheme of earth (adobe) construction system with ventilation space below [credits Alice Tavares]

Figure 2-7 - Ventilation space in the base of an adobe construction [credits Alice Tavares]

Other traditional construction systems lack ventilation space and present some problems due to the use of the floor girders above timber beams (which are inserted into the walls), which is a common occurrence in Turkish construction (Karababa F 2007). This placement hampers the inspection of the structure bellow, including the replacing of timber members that have deteriorated due to the lack of ventilation, which is a cause of structural degradation. The ventilation spaces in the base of the construction enable better control of fluctuations at the high moisture levels; they are responsible for the degradation of the timber elements, which are less resistant to the effect of humidity.

Although earth construction systems may have a number of shapes, the size of the openings had usually limited dimensions. The width of the walls varied in relation to the height of the building according to local environmental conditions, i.e., thicker walls in cold regions and thinner walls in warmer regions (Mecca S & Dipasquale L 2011).

The insertion of beams into the construction walls is another issue that was almost solved by various traditional construction methods. As for vernacular stone masonry or earth constructions, beams were placed outside the wall supported by buttress elements connected to the wall, in holes in the wall, resting above one or two timber bond beams, or resting on a timber beam and projecting outside the exterior line of the wall. The type of insertion that was employed for timber beams has implications for both the durability and the structural behaviour. Alberti’s treatise emphasises this subject and recommends that the number of voids in the walls must be as small as possible. The ventilation of the top of the beam inside the wall was a major difficulty that caused its degradation in many cases due to higher levels of moisture in this area. In addition, the degradation of the top of the timber beams causes a lack of stability of the floors and the connection between opposite walls, which has implications for the structural behaviour. This problem is also observed when the constructions (such as earth construction and stone masonry buildings) have a timber ring beam on the top of the exterior wall to connect the roof structure. Its degradation due to a lack of ventilation, a lack of roof maintenance and damages on the roof covering is one of the major problems of this type of construction. This problem is sometimes responsible for damage to the walls due to the introduction of horizontal loads by the variable action of the roof structure, which hinders the upper connection of the walls and can introduce out-of-plane movements, which are particularly relevant in seismic regions.

Concerns related to the construction of the walls and corners in vernacular architecture revealed some links to the treatises, such as the use of stone blocks and their imbrication, namely, in rubble masonry walls. Pilasters introduced in the architectural conception for the corners increase the width of the wall to strengthen this area. In some earth constructions, fired bricks were employed to strengthen the corners. The areas that were the most susceptible to degradation include the arches and vaults and the areas around the openings. The lack of care in the construction of these elements induces damage such as diagonal cracks. In addition, the distances between two openings and between the openings and the corners are important for controlling diagonal cracks and achieving greater structural performance (namely, in seismic regions), as demonstrated in the treatises recommendations and the characteristics of ancient construction systems.

The strengthening of the corner is observed in Italian rammed earth constructions of Piemonte and other regions, such as Alessandria (Mecca S & Dipasquale L 2011). Similar procedures were employed in the central region of Portugal in the adobe constructions basements of or in rubble masonry.

Other types of earthen architecture, such as wattle and daub, exhibit similar concerns with the stability of corners, namely, by placing diagonal timber elements in the corners to connect the timber columns and guarantee the stability of structures. Diagonal elements are also important in timber constructions as the lack of these elements can damage a building, as the example shown in Figure 2-8, in which the diagonal timber elements from an abandoned salt warehouse were removed. Damage to this traditional timber building was caused by the movement of the entire construction in one direction, which may lead to its collapse.

Timber buildings comprised one of the traditional construction systems with a higher level of growing standardisation and improvements in the method of construction (Tuomic RL

1979; Lewis N B 2006), which enabled the prefabrication of solutions from Scandinavian countries, Germany, Austria and England to attain a high level of production and exportation during the period between World War I and World War II (Beusekom J W van 2006). The system's main advantages are its simplicity, low cost, ease of construction and transportation. Another factor that influences the use of natural materials in construction is the need for other materials, such as steel for war equipment, which reduced these materials in construction at the time.

At the beginning of the 20th century, a particular interest related to the correct position of the timber elements in building construction and the need for standardised procedures for assigning working stresses to timber was evident. This situation attracted special attention to the debate about the best type of tests for obtaining the mechanical properties of timber (Tuomic RL 1979). Military housing, bridges, industrial plants, warehouses, and shipyard facilities employed timber wherever possible. The construction of some of these buildings was associated with specific rebuilding programs and was conceived as temporary structures with a maximum anticipated life of five years. After 36 years, some of these buildings remain (Tuomic RL 1979). The most frequent problem was related to changes in use and occupancy, which imposed different loadings than the loadings of the originally constructed buildings (Tuomic RL 1979). The same situation applies to many regions, in which timber constructions comprised the main traditional method.

Figure 2-8 - Traditional timber constructions (demolished) - Portugal [credits Alice Tavares]

The majority of domestic buildings in Turkey were constructed of wood until the 1960s (Doğangün A et al. 2005). As in many parts of the world, the adoption of reinforced concrete almost destroyed traditional construction practices. After the earthquakes of 1999, the interest in these typologies was renewed as this type of construction system demonstrated high seismic performance (ICOMOS 2006). Other regions with timber buildings, such as Paramaribo in South America and Suriname, which has been a World Heritage town since 2002, implemented programs for their maintenance. The interest of international organisations, such as UNESCO, for the relevant heritage of timber buildings of Zeyrek (Turkey), for example, shows that traditional timber buildings are deteriorated due to man-made influences, including abandonment, fire, poor choice of wood materials, material fatigue, economic insufficiency, air pollution, lack of laws to protect these structures and municipal indifference, defective workmanship and incorrect attempts of restoration, as noted by SeçKin (SeçKin N 2012). Similar problems are observed in many other regions of the world.

Even if this group of traditional construction systems is in a critical situation, the knowledge dissemination of their characteristics is considered an important action for their protection and the future implementation of proper rehabilitation programs, including the proper evaluation of capacity for buildings in seismic-prone regions.

2.3.2. Group B

Reinforced concrete (RC) irreversibly changed the panoramic of our landscape. The beginning of its use was a predictable and desirable occurrence during a time with strong links with architectural movements and technical demands. This use was easily widespread throughout the world and can be assumed to be associated with the globalisation of a product and a technique. The Modern Movement of architecture is a cultural value in many regions of the world with a growing interest in its protection, namely, in Europe and the USA. The high level of experience, in terms of space conception and technological improvements to support a new way of living, presented one of the most extraordinary global experiences in almost the same period of time. This contemporary multicultural technology reveals its vulnerability in seismic regions due to a lower level of caution in its construction methods and the questionable durability of materials.

The effect of the Industrial Revolution, World War I and World War II had a global impact on construction methods. At the beginning of 1915, discussions among politicians, technicians and industry were underway in the United States about the need to establish building codes to safeguard public health and safety. These concerns were also addressed in many other countries in Europe in relation to their construction codes (Tavares A et al. 2012b).

The need for quality control and the standardisation of procedures to achieve economic profits and maintain the industry imposed significant pressure on construction methods and the selection and creation of materials. The most astonishing new method was the progressive and vast introduction of reinforced concrete. In many countries, researchers attribute this introduction to the gradual decrease of the use of traditional construction systems. The migration from rural regions to urban centres also contributed to this situation in Europe, as noted by several international researchers, namely, researchers involved in the Terra Europae project (2011).

The desire for new architectural conceptions due to progressive lifestyle changes shattered the confines of traditional construction. The dissemination of reinforced concrete and Modernist architectural shapes in seismic regions presents potential problems for several reasons, such as the safety and the effective control of the construction process in these regions.

2.3.3. Group C

The architectural movement of Art Nouveau signalised a controversial change in the way living spaces were understood and the resistance to the impact of the Industrial Revolution. Despite its brief existence in many countries, its contradictory objectives of vast cultural and artistic promotion in relation to the significant complexity of production, including high costs, was an important step towards the introduction of new materials and techniques in construction systems (Tavares A et al. 2012c). The subsequent Art Deco and Modernism movements were responsible for the widespread dissemination of reinforced concrete. The models and their variations that were adopted in each country, however, present a similar link that can be assumed to be the most multicultural construction process. In some European countries, such as Italy and Portugal, both architectural movements caused a progressive change in construction, including the use of natural materials and traditional techniques in this period of time (Tavares A et al. 2013b). This aspect was also observed in France and Britain after World War II when these countries experienced shortages of industrial materials and the need to relocate affected populations en masse, which caused a brief revival of earthen construction (Guérin R et al. 2011). A similar situation occurred in Germany and Poland, in which specific rebuilding programs were implemented to house affected populations after World War II in association with policies of urgent rebuilding.

In Portugal, the introduction of reinforced concrete was gradual in some regions until the 1940s. It was initially employed for some elements or short beams on main façades. Subsequently, it was common in beams, columns and thin slabs despite the maintenance of the loadbearing walls of adobe or stone masonry in construction. In some regions of Italy, the elements that were considered to be the preservation of links with traditional materials and architectural volumetric configurations nationalism were considered to be a continuity of the social structure and “natural” acceptation of the new material in old frameworks to “improve” traditional systems as in Portugal (Tavares A et al. 2012c). Regionalist proposals that mixed tradition and restricted innovation were adopted in Portugal from the beginning of the 20th century. However, this period was very experimental in terms of technique and architecture, which prompted interconnected proposals between these two factors. As a result, buildings with Modernist aesthetic and traditional materials appeared in almost the same period (Figure 2-9) as mixed systems with reinforced concrete in old and traditional aesthetic shapes (Figure 2-10).

Experimental proposals with natural materials such as earth were constructed by great architects, such as Le Corbusier with a rammed earth proposal and Frank Lloyd Wright with an adobe proposal.

Mixed systems with adobe and RC are currently applied and analysed in seismic regions as New Zealand and Peru with specific proposals.

Figure 2-9 - Timber building, Modernism, Costa Nova, Ílhavo, Portugal [credits Alice Tavares]

Figure 2-10 - Old building with reinforced concrete elements [credits Alice Tavares]

2.4. Knowledge Dissemination through Treatises

Western architectural theory and treatises have their archetype in the De Architettura libri decem of the roman Vitruvius (30-20 B.C.) (McEwen I 2003; Rowland I 1999). According to Vitruvius, two fundamental concepts directly relate to robustness: the concept of proportion as the correspondence of members to one another and to the whole, which is measured by a “fixed part” (McEwen I 2003, pp.196), and the concept of symmetry, which is considered to be the fundamental condition for “coherence” and the result of calculated relationships, in which each part bears a measurable relation to every other part and the configuration of the whole (McEwen I 2003). In 1452, the *De re aedificatoria* (Borsi F 1989; Rykwert J et al. 1996) of Leon Battista Alberti (1404-1472), which was fashioned along the same structure of Vitruvius’ treatise, traces the current construction knowledge to the observation of roman archaeological sites and defines the aesthetic value in architecture as “the unity of all the parts founded upon a precise law and in such a way that nothing can be added, diminished, or altered but for worse” (Borsi F 1989, pp. 240). In the third book, Alberti explains this concept in terms of construction, considering that “the whole method of construction is summed up and accomplished in one principle: the ordered and skilful composition of various materials, be they squared stones, aggregate, timber, or whatever, to form a solid and as far as possible, integral and unified structure” (Rykwert J et al. 1996, pp.61). This structure shall be considered integral and unified only “when the parts it contains are not to be separate or displaced, but their every line joins and matches” (Rykwert J et al. 1996, pp. 61).

The concept that unity and integrity are fundamental to structural robustness and resilience is developed and applied in practice in at least two instances after the destructive earthquakes during the 18th century: the case of the *Pombalino* cage construction system of Lisbon, which was employed in the reconstruction of Lisbon (capital of Portugal) after the devastating earthquake of 1755, and the case of the *Casa Baraccata*, which was theorised by Milizia in 1781 and extensively applied in the Calabria region in the post-reconstruction after the destructive seismic events of 1783.

The authors of the Pombalino cage were military architects and civil engineers (Manuel da Maya, Eugénio dos Santos and Carlos Mardel) who emphasised the need for proportion and symmetry and introduced regularity and progressive standardisation as essential principles for designing a timber frame structure with infill materials. They incorporated the idea of a unified construction system, in which the connections had a particular importance to balancing and guaranteeing the distribution of loads in a seismic event and to prevent the collapse of the timber cage.

In 1781, two years prior to the strong earthquake of Calabria (Italy), Francesco Milizia (1725-1798) published his *Principij di architettura civile*, in which he proposed a composite timber framed building that was infilled with masonry, in which every element needed to be explicitly well connected and embedded with the remaining elements to resist seismic actions (Niglio O 2009).

In the following sections, a detailed review of these sources and other contemporary sources is performed with relevance to the list of connections. The objective is to identify the specific advice and provisions contained in the treatises regarding the role of each component, including size and relationship among parts, and compare them with the details of historic traditional composite construction as is currently observed in seismic regions.

2.5. Foundations

In the third book (1452), Alberti provides detailed advice on soil characteristics requirements to withstand the weight of a building, including the importance of underground inspections by trench digging and wells (Rykwert J et al. 1996) to identify the most suitable stratum to implant foundations, the presence of underground water courses or other instances that may hinder the erection of a building (Rykwert J et al. 1996). For construction on marshy ground with poor loadbearing capacity, he recommends the use of inverted stakes and piles that cover twice the surface footprint of the proposed wall, establishing the length of piles that exceed one-eighth of the planned height of the building and with a diameter that exceeds one-twelfth of their length. He also advises on the ventilation of basements and the foundations to prevent rotting (Rykwert J et al. 1996). He indicated that the foundation should be constructed of solid stones and constructed to a level of 0.30 m above the ground to prevent increased moisture and rain erosion. This assumption is subsequently presented in other treatises, such as the treatise *Istoria e teoria de tremuoti* by Vivenzio G (174?-1819), who advocated the use of a lower stone platform that is larger than the perimeter of the walls, considering the separation between the foundation and the base soil (Niglio O 2009). These concerns were disseminated for earth constructions and timber-framed constructions in many European regions.

In his report about the long Ferrara earthquake (1570-72)—Libri di diversi terremoti—Pirro Ligorio (1513-1583) stresses the importance of a sound foundation to guarantee the stability of a building during a seismic event (Guidoboni E 2005).

In his treatise, Milizia voices broader concerns that resemble a comprehensive hazard assessment of the salubrity of the area to its seismic hazard from exposure to floods, ground depressions, landslides, soft soil and other forms of unstable ground (Milizia F. 1813).

These concerns involved the shape and desired characteristics of the foundations of walls or columns. Alberti considered a detachment between a structure and its foundation despite the inclusion of the plinth as an element of the foundation (Rykwert J et al. 1996). The discontinuity of the wall foundations via the use of arches was addressed for pillars or columns for particular grounds characteristics (Rykwert J et al. 1996). The capacity of the ground to withstand the intended load of the building was also highlighted. For the stability of a structure, he recommended foundations that were wider than the thickness of the walls (Rykwert J et al. 1996), this idea was also recommended in the 18th century treatises, such as the treatise *La science des ingénieurs dans la conduit des travaux de fortification e d'architecture civile* of Bernard Forest de Bélidor (1697-1761), which also discussed the correct depths for the foundations (Bélidor B F 1754).

2.6. Walls and Openings

The Alberti treatise (1452) emphasised the need for a guarantee that the walls perpendicularly and completely connect as much as possible from the ground to the roof and the placement of the openings in such a manner that would maintain the strength of the structure. He also proposed keeping windows from the corners and noted that in ancient architecture it was customary to “never allow openings of any kind to occupy more than a seventh or less than a ninth of walls surface” (Rykwert J et al. 1996 pp. 27). The proportion of the openings was dependent on the distance between two columns. He also recommended the use of arched openings of the most suitable and durable form to “avoid having an arch of less than a semicircle with one seventh of the radius added” (Rykwert J et al. 1996, pp. 30), i.e., a raised profile. He noted that this design was the only design that did not require ties or other means of support and noted that “all the others, when on their own and without the restraint of ties and opposing weights, seemed to crack and give way” (Rykwert J et al. 1996, pp. 31). Alberti considered that attention should focus on the wall around the openings, which should be “strengthened according to the size of the load that should bear” (Rykwert J et al. 1996, pp.71).

Recommendations about corners, arches and openings were also provided in the treatise *Trattato del Terremoto* of 1571 by Stefano Breventano (1502-1577) (Niglio O 2009). In his book *Dialogo del Terremoto* (1571), Giacomo Antonio Buoni (1527-1587) detailed observations of damages to arches after the Bologna and Ferrara earthquakes (Guidoboni E 2005).

In the *Pombalino* constructions, which were constructed from 1756, special attention was given to the regular distribution and dimensions of the openings and the corners to comply with the official design plans of the façades. In 1758, a regulation that limited the height of the building and imposed a restriction on the element jutting out of the façades was published (França J-A 1989). The design plans of the interior also proposed regular dimensions with standardised measures for the timber, stone and iron elements. These plans enabled the prefabrication of the elements in the outskirts of Lisbon, which were transported to the *Baixa*’s construction sites when needed. This procedure resulted in cost reductions for materials, production and workmanship (França J-A 1989). The military civil engineer Manuel da Maya proposed a restriction on the height of buildings with two floors. Due to the social pressure imposed by the need for housing and construction profit, the allowable height range was extended to 4-5 floors, which prompted an urgent need for a seismic-proof solution (França J-A 1989). The allowable height of the building was also correlated to the width of the street to reduce the risk of injury to people by falling debris from buildings during an earthquake, to maintain a safe area to rescue people and to facilitate circulation in the immediate aftermath of a destructive shock.

Milizia in 1781 (Milizia F. 1813) also establishes similar correlations between the height of a building and the width of a street. He proposed that dwellings that were constructed along principal streets could have three floors, whereas the heights of dwellings along secondary streets should not exceed two floors (Milizia F. 1813). Although Vincenzo Scamozzi (1548-1616) had advised that a building should not be taller than the width of the adjacent street during the 16th century, Milizia considered that the adoption of a proportional measure was more appropriate (Milizia F. 1813).

After the 1783 Calabria earthquake, a seismic-proof solution for residential buildings was conceived by the architect Vincenzio Ferraresi and included in the treatise of Giovanni Vivenzio *Istoria e teoria de tremuoti* 1783 (Vivenzio G 1787). This solution had a specific urban connotation as it envisioned a two-storey building flanked by two single-storey buildings with the role of help supporting the taller building. Vivenzio argued that this solution was reasonable as the height of the construction would be smaller at street corners, less vulnerable and at a lower risk of obstructing the two streets (Barucci C 1990). His considerations were purely static and he overlooked the possibility that buildings of different heights would have diverse natural periods and stiffness values and could damage each other via pounding. In 1784, the *Istruzioni Reali* of the Borboni's Government of the reconstruction of Reggio Calabria, which included the proposals of Vivenzio, established the maximum height of buildings to be approximately 30 hand palms (Grimaldi A 1863; Tobriner S 1983). In large streets and squares, buildings with the addition of a mezzanine floor with no more than 9-10 palms were permitted (Grimaldi A 1863).

2.7. Corners and Wall Materials

Alberti considered each corner to be "half of the whole structure" and the point of onset of any damage or decay (Rykwert J et al. 1996). Thus, he noted that corners throughout the building need to be exceptionally strong and solidly constructed. Alberti emphasised the ancient practice of significantly thickening the walls at the corner by adding pilasters to reinforce the area “to keep the wall up to its duty and hinder it from leaning any way from its perpendicular” (Rykwert J et al. 1996). In addition, he highlighted the need for a system of quoins and longer with the same thickness as the wall to prevent detachment, which would extend into each of the walls at the corner in alternate courses that can support the remaining panelling (Rykwert J et al. 1996). In relation to the connections of the façades of adjacent buildings along a street he notes: “Stones left every other Row jutting out at the Ends of the Wall, like Teeth, for the Stones of the other Front of the Wall to fasten and catch into” (Rykwert J et al. 1996). This attention to the construction of the corners was also present in the treatises of Bélidor (Bélidor B. 1754) and Milizia in1781 (Milizia F. 1813), who highlighted the importance of this design due to the effect of loads on the corners in a seismic event (Milizia F. 1813).

Recommendations for the most appropriate use of materials in diverse parts of construction already existed in Vitruvius and cited by Alberti. Several other treatises and books had specific chapters dedicated to materials, such as the *L’Encyclopédie* (Diderot D & D’Alembert J, reprint - 1969), which was coordinated by Denis Diderot (1713-1784) and Jean Le Rond D’Alembert (1717-1783), who published several books from 1751 to 1772. This study intended to record different fields of knowledge, including information about construction practices, catalogues of construction elements and their organisation into construction systems, by considering their regional variations.

Another encyclopaedia related to existing building typologies that are seismically deficient is the World Housing Encyclopaedia (www.worldhousing-net.com), which was developed by the EERI with the contribution of many researchers from different countries over the past 15 years. This resource, which is available online, contains important information concerning vernacular traditional and modern housing construction systems in earthquake-prone regions of the world. The objective is to identify the specific construction elements and construction practices that render a particular system prone to earthquake damage and classifying them with respect to the EMS’ 98 vulnerability scale (Grunthal G 1998).

The introduction of tie rods in specific locations is a traditional measure that has been adopted in many regions to guarantee a better connection between two walls and between the walls and the roof or the floors (D’Ayala D et al. 2004). This measure would have a significant effect on the vulnerability, especially for taller buildings—four to six storeys—as demonstrated in a study of the traditional constructions of *Alfama*, which is a district of Lisbon (D’Ayala D et al. 1997).

The information about the treatises that were analysed in this chapter indicates an interesting aspect that is specific to walls. In his treatise (1452), Alberti considered one of the most important rules to be the construction of a wall on level and uniform ground, considering the regular size of the stones (Rykwert J et al. 1996). The explanation for this measure was associated with the assumption that imposed weight exerted irregular pressure on a structure, in addition to the inadequate grip of the drying mortar, which produced cracks in a wall (Rykwert J et al. 1996). After the Calabria earthquake (1783), Francesco La Vega noted similar concerns about the sizes of the stones to be included in rubble stone masonry and highlighted the need for a quality blend of the mortar (Tobriner S 1983). Milizia in 1781 (Milizia F 1813) emphasised the need for a uniform distribution of the weight for structural equilibrium, considering the quality of the materials (Milizia F 1813).

Observing the ancient constructions, Alberti concluded that the infilling of the walls was based on the rule that imposed every single section of infill with a maximum length of approximately 1.52 m, without being bonded in some areas with a course of long- and broad-squared stones (Rykwert J et al. 1996). He considered that these squared stones acted as “ligatures or muscles, girding and holding the structure together and also ensured that should subsidence occur in any part of the infill, either by accident or as the result of poor workmanship, it would have a form of fresh base on which to rest” (Rykwert J et al. 1996 pp. 72). This construction detail can be observed in many Roman constructions; in some cases, the stone is replaced by brick layers along the wall, which are composed of thin ceramic elements. In vernacular constructions in seismic regions, this form of lacing is achieved by the use of timber elements that are laid along and across the wall, as discussed in the next section. Milizia also recommends the use of “a succession of ties made of charred olive wood, binding the two faces of the wall together like pins, to give it lasting endurance” (Payne A 1999, pp. 45).

Another interesting issue, which is related to different types of stone masonry, is the recommendation to improve the durability of the structure. Alberti emphasised the need of each course of the entire wall be composed of squared stone. If it was necessary to fill the gaps between the two vertical plans of the wall, the courses on either side should be bonded and level (Rykwert J et al. 1996). He also recommended the use of spaced block stones that span across the wall and connect both vertical plans “to prevent the two outer surfaces that frame the work from bulging out when the infill is poured in” (Rykwert J et al. 1996, pp. 73). This recommendation is employed in vernacular construction with stone masonry and public buildings, dwellings and walls. It is also associated with the stability of the structure and the need to improve the mechanical behaviour of the entire wall to unify its elements as much as possible.

In relation to the infill materials, Alberti emphasised the ancient knowledge, considering that small stones join and bond better than large stones. He also recommended that the infill did not contain stones that weighed more than approximately 327.45 g and that all materials should be carefully bound and filled (Rykwert J et al. 1996) to maintain the stability of the wall.

Alberti noted a similar concern for the construction of the cornice to tightly bind the walls. For this reason, the characteristics of the stone employed in this area should be carefully considered: the blocks should be extremely long and wide, the jointing should be continuous and well-constructed and the courses should be perfectly level and squared (Rykwert J et al. 1996). The care with this particular component of the construction is justified by Alberti, who assumes that this area is a potential vulnerable area of the construction where “it binds the work together at a point where it is most likely to give way” (Rykwert J et al. 1996, pp.74) in addition to its function of the upper protection of the wall to prevent damage by rain. This particular aspect can be observed in vernacular architecture with stone masonry and in earth constructions with the use of stone or layers of thin tile bricks, in addition to the protection of the eaves.

2.8. Roof and Protection against Fire

The connections between the walls and the roof structure received particular attention in the treatises and practice of reconstruction in seismic regions in the 18th century. The *Pombalino* cage considered specific connections that involve the structure of the roof. According to Lisbon regulations at the time (from 1756), no element was permitted to protrude from the roof, with the exception of a kitchen chimney. A similar restriction was imposed in Calabria (Italy) in 1784, which additionally prohibited the construction of cupolas and steeples in churches (Barucci C 1990).

An extensive proportion of the damage experienced in the events of Lisbon (1755) and Reggio Calabria (1783) was caused by fires that developed in adjacent houses after the earthquake.

The regulation that facilitated the reconstruction of London after the Great Fire of 1666 (Aires C 1910) was known by the Portuguese civil engineers who were responsible for the reconstruction of Lisbon. To prevent fire from spreading from house to house, the civil engineer Manuel da Maya (1756) proposed that the walls that divided the properties within an urban block should be constructed above the level of the roof (Aires C 1910), as presented in the drawings of Eugénio dos Santos. A similar rule was introduced in Istanbul during the reconstruction of the Fener-Balat area after damage by an earthquake and subsequent fire in 1894 (D'Ayala D 2004a).

Finally, the enthusiasm and admiration for classical architecture developed in the post-medieval period and the Renaissance was fostered by Alberti's treatises. This created the perception of stone masonry construction as the most durable and robust form of architecture and the only worthy material for formal and celebrative Architecture, royal and nobles palaces and religious buildings; brickwork and timberwork was relegated to ordinary construction. However, earthquake engineering identified deformability without failure or with controlled failure, emphasizing ductility, as essential attributes of earthquake-resistant constructions. These attribute could be achieved by the coupling of masonry and timber elements.

2.9. Seismic Positive Performance of Traditional Composite Structures – an example of a multicultural link

As discussed in the previous section, the treatises of the Enlightenment and the early engineering solutions for the reconstruction of buildings after major destructive earthquakes in the second half of the 18th century all converged towards mixed construction systems with timber frames infilled with masonry as the most suitable construction in seismic regions. From earlier times examples of composite timber-masonry structure are mentioned by Boethius (Boethius A 1978) in the reconstruction of the ancient Etruscan civilisation settlement in central Italy, which dates to 600 B.C. These structures were composed of sun-dried brick and half-timber on stone foundations (Boethius A 1978). Additional examples of composite systems exist in several regions of the world that are prone to seismic hazards. These systems are usually the result of the organic development of vernacular and traditional architecture that has been altered after a destructive earthquake to withstand the next event. Their actual seismic resilience is a direct function of the relative capacity of timber and masonry as primary and secondary bearing structures or vice versa. As several vernacular examples, *bahareque* in El Salvador, *quincha* in Peru, *taquezal* in Nicaragua, *pontelarisma* in Greece, *taq* or *dhajji dewari* in Kashmir, and hatil and *hımış* in Turkey. Their construction details and seismic performance can be compared with the corresponding elements of the Pombalino Cage and the *Baraccata* house, which are two early examples of engineered seismic construction.

In the case of the *Pombalino* and *Baraccata* systems, the solutions that were selected to ensure robustness were also conditioned by the need to rebuild many dwellings within a short period of time with local available material. A review of the progress of reconstruction in Reggio Calabria indicated that, compared with the original design, less timber was employed in the reconstruction due to shortages of the material in the immediate region. In Lisbon, a more expedite and economic rebuilding was achieved by the use of debris materials from the collapsed constructions. Attempts were made to standardise element configuration and connections to enable the necessary regularity and a quicker production of the framing elements.

Construction systems that used timber as a framing structural material with masonry in-fill have two important characteristics: first, the use of a lightweight construction system that is easy to build with the capability of greater height and more available space due to thinner walls; and, second and improvement in the ductility of the entire system to withstand seismic loads.

However, mixed systems with timber without anti-seismic capacity can be observed in many other regions of Europe; some systems even show similarities with Oriental systems that are considered to have these characteristics, such as the *hımış*. Despite the ductility of timber, many European systems do not have the necessary regularity or the number of bracing diagonal elements or specific connections to withstand seismic events.

As mentioned in the previous section, the connections among the orthogonal walls are critical to ensure a global behaviour of the system; this importance has been emphasised over time in treatises and in practice. This connection in masonry structures was typically ensured by the insertion of quoins and stone keys and was subsequently reinforced by the use of iron ties and anchors. The connections among walls are fundamental not only for the robustness of the system and to keep the walls in plumb but also to resist lateral loadings produced by wind or earthquakes. By the ensemble of the walls with a box-like behaviour, the action can be transferred from out-of-plane behaviour to in-plane behaviour. Thus, particular construction solutions are aimed at strengthening this connection, implicitly testifying how buildings behave under seismic loading and developing efficient methods to resist these loadings. In many of the traditional and historic timber masonry composite systems employed in earthquake- prone areas, the role of timber is extended from framing to reinforcing.

Tracing the presence and evolution through history of these construction solutions and identifying the conceptual link between a construction system that is primarily composed of masonry reinforced with timber to a construction system that is composed of timber framing stabilised with masonry will help us understand the degree of seismic performance awareness on which these traditional systems were constructed and how they have influenced previously engineered solutions.

The basic mixed system is composed of a series of masonry courses that are interlaced by timber logs, which are horizontally placed along the sides of the wall and meet at a corner with another couple of timber logs that are placed in a similar manner along the perpendicular wall. The timber that forms the couple of runners is connected by transversal elements at regular intervals, whereas the two couples are sometimes connected at the corner; otherwise, they are simply placed on top of each other. The connections among the timbers are sometimes achieved by scarf joints, simple cuts, or nails.

Palyvou K. (1988) describes an ancient mixed structure with timber that belongs to a construction in the Akrotiri settlement (1650 B.C.) on Santorini Island (Palyvou C 1988).

The construction had exterior walls of stone masonry and interior walls that were reinforced by a timber structure, loadbearing frames around the door and window openings (Touliatos P 2000). According to Touliatos's interpretation, the objective of this construction is to improve the tensile capacity of the stone walls by timber grids embodied in the walls connected to vertical studs (Figure 2-11). Touliatos assumes this design to be an ancient anti-seismic solution (Touliatos P 2000). The ductility of the walls, the type of confinement of the material infill and the regularity seem to be relevant characteristics in this evolutionary process.

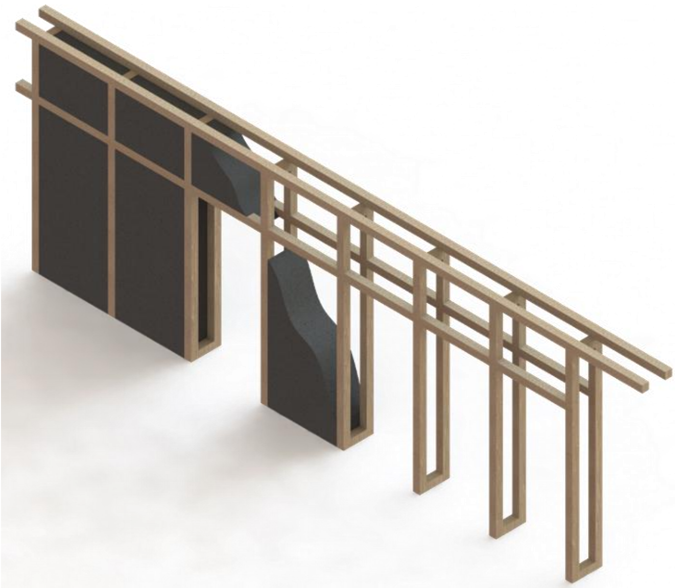

Figure 2-11 - Timber structure based on the drawings of Palyvou K. (Palyvou C 1988) of the ground floor construction "Xesti 3", without scale [credits Alice Tavares].

Buildings with laced bearing walls on the ground floor level and infilled frames for the upper storeys were commonly employed during the Ottoman Empire and can be observed in many variations throughout Greek regions, such as Pelion Epirus, Macedonia and Central Greece, and some Aegean islands, such as Thasos and Lesvos, which experienced significant urban growth (Karydis N 2003). This variation on the use of horizontal timber elements is visible in the exterior walls of a traditional Greek construction system examined by Sakellaropoulou (Sakellaropoulou M 2009). In many regions of Greece, adobe masonry was constructed as confined bearing masonry with horizontal timber ties, which may have been visible at the façade of the wall. The timber ties were spaced from 0.70 -1.00 m inside the masonry laid at the level of the floor and/or at the openings (Bei G 2011). The main characteristic of this solution, however, is the use of thinner horizontal elements that were placed on both sides of the wall and regularly spaced throughout its entire height. These longitudinal elements are transversally connected with the timber elements. The introduction of these horizontal elements improves the total behaviour of the system and the confinement of the infill material.

As a main concern, the horizontal timber elements were placed at the base of the structure, at the window sill and the window header height, at the level at which the floor beams were fixed to the masonry and at the coronation of the walls (Sakellaropoulou M 2009; Touliatos P 2004).

Another relevant characteristic is the solution of the corner. The couples of horizontal timber elements that belong to two orthogonal walls at the same level are connected at the corner and sometimes extend beyond the exterior face of the wall. This connection of double timber elements can improve the stiffnesses of the walls in the corner while offering the possibility of limited horizontal movement, which facilitates energy dissipation during a seismic event and limits deformation and cracking.

Masonry structures laced with horizontal timber elements are also observed across the earthquake-prone regions between the Eastern Mediterranean and the foothills of the Himalayas (Touliatos P 2004), which comprises a large geographical area in which these forms have been developed for several centuries as *taq* (Kashmir) or *hatil* (Turkey) (Sakellaropoulou M 2009).

The main difference between the Greek system (Figure 2-12) and the *taq* system is that the latter is dependent on the dimensions of the horizontal timber elements, which are larger and assume the function of beams that line the walls. The distance between the horizontal timber layers is significant and the layers generally have connections with the beams of the floor.

Figure 2-12 - Greek laced masonry based on the work of Sakellaropoulou M. (Sakellaropoulou M 2009), without scale [credits Alice Tavares].

The tradition of lacing masonry with timber—either squared or in the round—was common throughout the territory of the Ottoman Empire.

Hughes considers the Turkish *hatil* system, which is related to the *cator* and cribbage systems of northern Pakistan (Hughes R 2000), despite its difference in the number of timber elements, which may be less in the *hatil*; the *hatil* also exhibits the same type of timber longitudinal elements, which are embedded in the walls. In the cator system, Hughes explains that the timber elements generally have a square section that ranges from 50 to 120 mm and horizontal beams that are placed on both sides of the wall at vertical spacing from 0.30 m to 1.30 m. “In better constructed walls the face timbers are tied together through the wall thickness with joined/nailed cross pieces at 1 to 4 intervals. Where the beam is of insufficient length for the whole length of the wall, two or more pieces are connected with tension resisting scarf joints. Breaks in the integrity of the ring beam may occur at doors and windows” (Hughes R 2000, pp3). The image of Alti Fort Tower in Hunza, Pakistan, as presented by Hughes, shows a denser use of horizontal timber elements given its defensive use. The *cator* system (Figure 2-13) also reveals distinct similarities with the Greek traditional system; for example, the system in Lesvos Island. Both of these systems employ horizontal timber elements, such as beams that face both sides of the width of the wall. In addition to the function of confining the masonry infill, a more regular spacing of the horizontal elements and their larger dimensions yields more robust wall corners compared with the Greek system.

Figure 2-13 - Scheme based on the work of Hughes R. (Hughes R 2000) of an antique defensive tower wall, Pakistani *cator* and cribbage system, without scale [credits Alice Tavares].

Sakellaropoulou emphasises that the placement of horizontal timber elements within masonry bearing walls not only increases the structural resistance of each wall but also to ensures the continuity of the load transfer between two masonry walls (Sakellaropoulou M 2009). The objective of introducing ductility to the structure, adding cohesion to both sides of the wall and preventing the disintegration of the infill materials is the most important role of the horizontal timber lacing. This construction type is also observed in the earthquake-prone area of Peru, where timber logs in the round are utilised to lace adobe brickwork, and in Nepal, where the bracing system confines the masonry panels adjacent to the windows and is connected to the horizontal structure with pegs. In the Nepalese system, the brick masonry walls only form the outer shell of the building, whereas the interior is divided by timber frames.

The coupling of the timber frame and the masonry is the characteristic of a second set of similar solutions for earthquake-prone areas. The previously mentioned *Casa Baraccata* (Figure 2-14) of the architect Vincenzo Ferraresi, which was published by Vivenzio G. in 1783 (Vivenzio G 1787), shows two horizontal ring beams at both sides of the base of the walls at the platform level of the ground floor, which was a minimum of 0.60 m above the ground. Ferraresi's drawings show the same connection arrangement between the two orthogonal walls, which had two horizontal timber beams, as described for the *hatil* system. However, in Baraccata's drawing, the transversal connecting elements appear on the same plane as the timber beams and are dovetailed into them to form a continuous ring beam. The major difference is the presence of four vertical posts at the corner, which are braced by the end of the beams of the two orthogonal walls. Vivenzio's solution assumes that the wall material infill can be cut stone linked with cramps to connect all elements along the horizontal layers (as employed in some Roman constructions; for instance, the masonry blocks of the Coliseum (McEwen I 2003; Croci G & D'Ayala D 1992) for two-storey to three-storey buildings. In addition, the frame panels are regularly braced with diagonal elements that surround the openings. Vivenzio also proposes a second solution for a one-storey building, with a post with a square cross-section of 0.20×0.20 m2 to maintain a regular distance between them of approximately 3.0 m for one direction and less than 2.0 m for the spacing in the other direction. The diagonal elements had sections of 0.10×0.10 m2 combined with horizontal elements with sections of 0.15×0.7 m2 to form the timber frame.

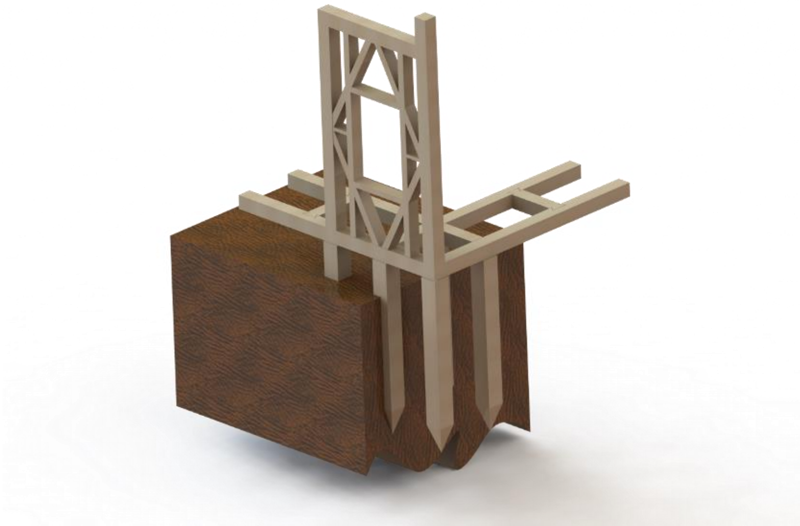

Figure 2-14 - The lower part of the system *Casa Baraccata* (1783) based on the drawings in the book of Vivenzio G. 1787 [credits Alice Tavares].

Although some researchers have emphasised the similarities between the *Baraccata* and the *Pombalino* cage, they are characterised by a different bracing system; thus, they behave differently from a seismic point of view. In particular, the cross bracing of the *Pombalino* cage ensures a continuous truss action, which is not present in the *Baraccata* given the layout of the elements. The *Pombalino* cage is characterised by a regular timber-frame structure with standard dimensions, masonry infill, and specific connections to the floors, roof and exterior walls. The adoption of Saint' Andrews crosses in the majority of the wall panels increases the stability of the structure, which is an important measure in seismic-prone areas.

The *Casa Baraccata* was introduced in Calabria after the earthquake of 1783. This type of construction system is described by some researchers via the presentation of buildings that primarily date from the end of the nineteenth century and the beginning of the twentieth century (see for example: (Bianco A et al. 2010; Mecca S & Dipasquale L 2011). However, subsequent solutions reveal substantial differences compared with the eighteenth century solutions of Vincenzo Ferraresi, namely, in terms of the type of connections.

According to Mecca (Mecca S & Dipasquale L 2011), these solutions for the Baraccata had a timber frame with vertical, horizontal and oblique chestnut or oak beams placed at a distance of approximately 1.20 m to create a truss structure. A weave of wickers and reeds was bonded to the main structure with thin chestnut laths and covered with an earth mortar. In some cases, adobe filled the structure. For the interior walls, the incannucciata technique, which consists of a mesh of interwoven canes or branches covered by a clay plaster, was frequently employed (Mecca S & Dipasquale L 2011).

In the Baraccata solution, “some particular issues as symmetry, reduced heights construction and the use of a timber structure were positive aspects in terms of enhancement of seismic behaviour,” as described by Tobriner S (Tobriner S 1995, pp.72). However, the symmetry was incomplete due to the position of certain interior walls, which could induce a torsional effect. In addition, the different volumetric heights of the building could also induce damages in a seismic event.

The construction system *pontelarisma* (Figure 2-15) is an ancient solution that was observed on Lefkada Island (Greece). As described by Sakellaropoulou (Sakellaropoulou M 2009) and Karababa (Karababa F 2007), the loadbearing masonry walls of the ground floor comprised double-leaf walls with a width that ranged from approximately 0.5-1.2 m and a height that ranged from 2.5 m to 3.0 m; they were constructed from local stones (sedimentary rock or limestone). The external leaf is constructed of roughly cut stones, whereas the masons utilised quoins for the corners of the buildings to ensure bracing between the walls. The internal leaf is composed of rubble stones, whereas pieces of bricks or small stones mixed with mortar are employed for the infill between the two leaves (Sakellaropoulou M 2009). The common plan dimensions are 4.0-5.0 m along one axis and 7.0-15.0 m along the other axis; the openings symmetrically arranged.

Karababa (Karababa F 2007) describes the foundations as solid structures that prevent the differential settlement of the upper superstructure. On the top of the stone masonry walls around its perimeter, a timber beam is placed inside the wall to which is connected the timber frame of the upper floor. Steel ties are employed to secure the connection between the masonry wall and the timber beam using a regular spacing. Steel ties are also installed to secure timber elements around the windows and openings (Karababa F 2007). The floors have timber joists with cross-sections of 0.20×0.20 m2, which are placed at 0.40 m centres and mortised into the sole beams embedded along the perimeter of the stone masonry (Karababa F 2007).

The loadbearing timber frame of the ground floor consists of columns and beams that are arranged at the inner perimeter of the stone masonry wall and 0.5-0.10 m from the wall, which facilitates independent movement and the deformation of the two systems during a seismic event to prevent pounding effects (Karababa F 2007). The cross-sections of the timber columns range from 0.15-0.20 m2 (Sakellaropoulou M 2009) or from 0.12 m and

0.22 m and are constructed on stone bases that are secured onto them with steel ties embedded into the stone (Karababa F 2007).

A timber frame of the upper floor, which is linked by a horizontal sill beam with a cross-section between 0.12 m and 0.20 m, is placed on top of the floor joists. Each wall is composed of a grid that is divided and erected at 1.0-2.0 m centres (Karababa F 2007). The exterior posts have a cross-section that ranges between 0.12 and 0.22 m. The elbows or "bratsolia" provide stiffness at the corners between the posts and beams (Sakellaropoulou M 2009) and are cut from a single piece of olive tree branch (Karababa F 2007). The roof structure usually consists of a truss system that is arranged in more than one dimension to ensure adequate stiffness (Karababa F 2007).

Figure 2-15 - *Pontelarisma* based on the work of Touliatos (Touliatos P 2004) and drawings of Sakellaropoulou (Sakellaropoulou M 2009), without scale [credits Alice Tavares]

The main difference between this solution and previously discussed solutions is the idea of a double method of support via the use of an exterior stone wall and interior timber columns. The main objective of this structure is to guarantee that the upper floor will not collapse in a seismic event as it is supported by an interior timber structure.

The underlying idea of the acceptable collapse of the stone masonry wall is also presented in the *Pombalino* cage. This predicted collapse is restricted to the exterior wall of the ground floor. The identical objective of resistance of the timber structure to seismic loads without collapsing is to ensure the safety of the people inside the building.

Pontelarisma has another link with other types of traditional construction: the vertically aligned double timber beam. Between these two beams, the floor structure was placed; it consists of timber beams with regular spacing that may have the tops outside the exterior vertical alignment of the wall with the purpose of controlling the effect of the horizontal loads and restrict structural movement without collapsing. This characteristic is shared by other traditional solutions, including the insertion of diagonal elements that are strategically placed in the construction, as observed in the *hımış* solution (Figure 2-16), which is a Turkish traditional construction system that is employed in the western Anatolia region and Marmara.

The *hımış* solution has a skeleton formed by vertically and diagonally placing wooden posts. The resulting space is filled with infill materials such as fired clay bricks, adobe blocks, or stone, which can be easily and economically obtained in the region. The use of mud mortar for the infill masonry is also widespread (Diren D & Aydin D 2000).

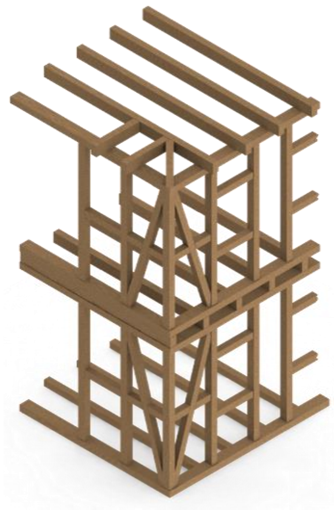

Figure 2-16 - Scheme of a corner of the *hımış* construction system based on the work of Bilge Isik (Isik B 2006) without scale [credits Alice Tavares]

Hımış has rubble stone foundation walls that are reinforced by timber beams placed on the interior and exterior faces of the wall at a distance approximately 1.0 m apart, which is a tradition that dates to prehistoric periods in Anatolia (Sahin N 1995). Sahin affirms that the main function of the timber beams was to form a frame around the masonry and to confine and ensure the unity of the wall (Sahin N 1995). The base of the foundation was sunk more than 0.45 m below the ground surface (Akan A 2004).

The ground floor was of stone or adobe masonry and the upper floor has a timber frame construction defined by two main timber beams—a header and a footer—which are linked to vertical timber posts with cross-sections that range between 0.12 × 0.12 m^2 and 0.15 × 0.15 m^2 with 1.5 m intervals (Isik B 2006). Between these loadbearing main posts, intermediate vertical elements are spaced every 0.60 m and horizontal elements to hold the infill with cross-sections that range from 0.6 × 0.12 m^2 to 0.6 × 0.1 m^2 (Isik B 2006). Diagonal

elements with the same cross-section of the main posts connect the foot beam to the main post and have a relevant function of the stability of the entire structure (Isik B 2006).
The infill material may include fired clay bricks, adobe blocks, or stone, which can easily and economically be obtained in the region. The use of mud mortar for the infill masonry is widespread, and the walls are either left exposed or plastered with mud and then whitewashed (Diren D & Aydin D 2000).
In Turkey, mixed construction techniques within single buildings are common and houses are frequently designed with the laced bearing wall (*hatıl*) construction for the ground floor level and *hımış* for the upper storeys (Lagenbach R 2003).

This review of existing composite structural systems in earthquake-prone regions helps to identify recurring elements that are recognised as essential for a successful seismic performance. These elements can be summarised as the timber lacing (or ladder) that is composed of two squared runners along the top of the wall within its height at regular intervals and connected by transversal elements. The connection of these ladders, pertaining to orthogonal walls at the corner, was constructed using simple nails or lapped or scarfed joints. In earthquake-prone regions, the progressive introduction of timber frames to work in conjunction with or independent from masonry walls, suggests the use of two separate systems: the first system is to resist gravity loading—the masonry— whereas the second system is to resist seismic loading. In these cases, the masonry is only used as a plinth to isolate the timber frame from the ground and prevent its decay.

2.10.The international classification of heritage at risk

2.10.1. Cultural value in risk – diagnosing causes

The analyses of the proposals for heritage integration at risk list are relevant to the understanding of the motifs of threatened cultural values of built heritage. This analysis was considered as a starting point to establish the orientation of the research. Of the cases that were analysed for different countries, it is emphasized a valuation of the threat of two main issues—authenticity and integrity—which are two aspects that are also addressed in proposals for World Heritage classification. The background reflects an approach that is primarily based on cultural value and does not overlap with the economic value. The concept of Cultural Value is described in the Burra Charter (1999): cultural value comprises the aesthetic, historic, scientific, social or spiritual value seized by past, present and future generations. The cultural value expressed by the materiality of the well, its structure, context, meaning and use, and the places and objects associated with it. It is a reading of the “object” with an effective framework that underlies its significance. Although this research does not intend to address all documents or Charters that address cultural value, this specific Charter reveals the complexity of the protection of the built heritage and the research that is required to achieve the sufficient knowledge for such a broad objective.

2.10.2. Areas of risk of loss of cultural value and diagnosed causes

In practice, a greater ease of acceptance/understanding of the public opinion of the protection of the cultural value of monumental buildings has developed; however, difficulties have emerged in this sector, which are presented in this section. Other sectors have been considered to be equally relevant for an approach by presenting the most relevant to the study base (only based on built heritage, despite increasing concern for defending the natural heritage):

- built monumental and public;
- historic centres;
- agro-industrial environment;
- vernacular architecture;
- Modernist/Modern Movement architecture or contemporary.

In this study, a survey of the arguments from the UNESCO and ICOMOS reports were prepared to identify risk situations. Other national reports (Portugal) for each of these sectors, which include 2000 case studies to 2014, were analysed. We present a summary of the major causes that underlie the risk of loss of cultural value. The findings are associated with ICOMOS and UNESCO reports from the following countries (ICOMOS, UNESCO 2000-2014): Australia, Bolivia, Bulgaria, Canada, China, Colombia, Côte d’Ivoire, Cyprus, Cuba, Czechoslovakia, Ecuador, Egypt, France, Georgia, Italy, Iran, Japan, Lithuania, Macedonia, Mali, Malta, Myanmar, Nepal, New Zealand, Panama, Peru, Republic of Slovenia, Romania, Slovakia, Turkey, Uganda, UK, USA, Venezuela, Yemen and Yugoslavia.

2.10.2.1. Risk causes of loss of cultural value in monumental or public building

Monumental or public buildings are primarily the responsibility of public or governmental entities. The positive aspect of the increased awareness of the population to its preservation and as this protection practice is older than the current built protection is important but manifests itself insufficient. In terms of risk, we equate budgetary constraints for the protection or conservation. The reports indicate that the Heritage sector remains at risk due to the following reasons:

- Demolition threat;

- Impact of planned urban development on the area where the building is located;

- Real estate interest in the building - new uses, new height, new building density;

- Placement of infrastructure or new buildings in the surrounding or along the perimeter protection with great visual impact irreversibly damages the environment of the monument and its scale in the territory. Placement of new infrastructure with great impact in terms of road traffic near the monument or public building;

- The dismantling and scarring of historic buildings. In their place, the desire to rapidly and build at low cost and produce modern architecture that is ad hoc, chaotic, and characterised by poorly constructed reinforced concrete buildings that are detrimental to the fabric of the historic areas;

- Floods caused by storms/heavy rains or interventions in watercourses surrounding the building, which does not include adequate measures to the rainy season/winter. The damage observed at the highest levels of flooding may be aggravated when the water levels decrease by complementary phenomena—destabilisation of foundations, increased fluids upwelling through capillary action in masonry, dissolving of mortars, and potential weakening of structures, salt migration, acceleration of chemical alteration of the materials, and risk of alteration of works of art, murals, and furniture;

- Climate change and pollution (effect of moisture penetration and salt), seismic action and vehicle vibration action with a lack of technical and scientific studies to anticipate the effect of the damage and establish preventive or corrective measures that are specific to the protection of the monument;

- Lack of suitable program and financial funds for management and maintenance;

- Lack of regular inspection to identify necessary short- to medium-term intervention measures, including consolidation and structural reinforcement or restoration, as well as the evaluation of the foundation and ground conditions;

- Lack of timely conservation measures, which enable the decay of materials and causes irreversible loss of coating layers; some layers have high artistic value or significance;

- Threat to the coherence and integrity of the monument/building via new interventions, some rehabilitation or adaptation, with attached intrusiveness criteria;

- A recurrent danger of the deterioration of this historical architecture, especially involving the roofing vaults and walls; stabilisation is critical due to the threat of structural collapse. The poor state of conservation of the heritage of many buildings is partly caused by extensive neglect by the owner, which is a government or public entity in most cases.

- Many conservation and restoration projects in some countries are large-scale renovations or complete reconstructions. These renovations damage or obliterate the original fabric that they intend to “preserve”, which may be attributed to international uncertainties over definitions of conservation; however, greater sensitivity is needed. If the most sophisticated and cutting edge conservation techniques, which are pioneered in Europe and elsewhere, may not always be transferable to the heritage of some countries, a minimum care of authenticity should be expected when third-world and undeveloped countries are involved.

- Problems of insecurity and structural decay of materials with a particular impact due to loadbearing elements and a particular impact on roofs and facades;

- Commenced but never-finished restoration works create distinct challenges. The continuity of disuse of a building is another level of neglect.

- Problems in the installation of infrastructures (electric, equipment, and thermal devices), which damage the walls, floors or coverings.

- Fact-finding has revealed that more damage had been inflicted on covering layers, such as mural paintings, due to ‘cleaning’ work that was undertaken in total contradiction to the scientific recommendations;

- Changes in the responsible party/owner entity without the establishment of an utilisation program, maintenance plan and promotion of the monument/building.

Inconsistencies in terms of jurisdiction and competence in building management may exist. The loss or lack of role assignment is identified as a risk for the conservation of a building and the allocation of new functions that comprise substantial changes due to massive demolitions or failure to retain significant elements;

- Route of financial funds in interventions that does not include adequate prior assessments, which provides the necessary promotion of the monument to a volume of visitors that progressively offsets the investment, particularly in relation to infrastructure and accessibility immediately after the monument is closed;

- Problems with the monument management/building due to a lack of application of appropriate guidelines and coordination at the national, regional and local levels. Problems due to a lack of contemplation of scientific criteria in selecting and implementing interventions (rehabilitation and adaptation) and a lack of preparation and technical and scientific competence of decision-makers/managers/officers/politicians.

The findings conclude that a lack of public awareness remains and difficulties in the access of sufficient financial resources and the preparation of sustainable management plans and their application, which also involves a lack of preparation and technical and scientific competence, are expected. A lack of guidelines and manuals that can aid in the management and preparation of a budget to satisfy urgent needs is evident. The unbalanced urban development with visual impact in the monument is another problem. If this type of heritage remains a relevant problem, the situation with the other heritage sectors presents a higher level. The owner/responsible for this type of heritage are the same entities that are responsible for proposing legislation and establishing guidelines for the funding and regulations for the protection and conservation, which involve all other participants.

2.10.2.2. Risk causes of loss of cultural value in the historic centres

The historic centres or urban centres with relevance in terms of cultural value are under the jurisdiction of regional and local authorities. The identified problems reveal a lack of proactive measures from the responsible entities in terms of legislation, construction regulations that are specific to the built heritage, control of interventions, and education and promotion of the awareness of the value of the heritage. The pressure of economic groups takes advantage of the gaps in legislation and regulations or urban plans without criteria about the conservation of heritage and imposes a high level of changes in the historic centres. The technical field presents difficulties to attain good levels of cultural value preservation. Negative impacts on the social issue of the historic centres and the lack of maintenance actions or conservation generates a decrease in high levels of authenticity and integrity of these areas.

Under the responsibility of the governments and local authorities/entities, the following problems are noted:

- Failure to adopt international guidelines of ICOMOS or UNESCO or the recommended Charters in some circumstances in procedures accompanied by these leading organisations;

- Insufficient or inadequate protection legislation and a lack of the proper definition of a buffer zone and the interaction with the remainder of the historic centre;

- Insufficient conservation regulations or standards of conservation inadequate intervention to old construction;

- Unsustainable or uncontrolled urban development (includes no contemplation of preserving cultural value in their development objectives);

- Construction of motorways, airports, bridges or dams without prior survey of the area to be affected by the project; consequently, the silhouette of the historic city is affected negatively;

- Effect of policy changes and actions on the use of heritage as a political promotion object, which does not enable a real action for long-term protection and conservation;

- Economic revitalisation via cultural tourism or the development of other activities and by the business plans of powerful investors, who want to exploit the central areas. This option will probably improve the economy of the settlement by creating well-paid jobs for the inhabitants (not always, sometimes only for foreigners) but it will also destroy an important aspect of the villages and their landscapes;

- Changes to the level of urban development in the historic centre, particularly with the integration of large infrastructure such as shopping centres and the construction of large car parks, large shopping centres or large hotels in the historic centre, which force a massive demolition of old construction with risk for the loss of integrity as urban space that is classified as Heritage, and the installation of new infrastructure with a consequent increase in traffic, pollution and vibrations;

- Frequently, reconstruction in historic town centres produces changes in image and character, as demonstrated by the enlargement of structures and changes to building density;

- Uncontrolled migration flows by exponential population growth in the centre or desertification of the centre. Excessive growth has caused overcrowding of older areas, and desertification has resulted in vandalism and a lack of security. Both situations have negative impacts on the conservation of historic areas;

- Lack of criteria for the demolitions, which includes a complete and proper assessment of cultural value possessed by particular buildings, group of buildings or infrastructure, to evaluate the impact of irreversible loss. In many cases, the old houses are being demolished based on reports by technical staff who are not trained in historic preservation and do not have the necessary skills to evaluate the security level of the construction. A complete report with the precise values of the *in situ* assessment is unavailable. In addition, the forced migration of the resident population for the installation of new layers of populations or new activities (trade and tourism) or new economic groups creates the loss of traditional activities and ancient customs;

- Construction of new buildings or "rehabilitation" of old buildings via demolition of the interior for residential typologies that do not fit in the real market result in a “rehabilitated” and vacated buildings and a return to the process of decay and vulnerability to vandalism;

- Abandoned buildings. Lack of preventive measures that reduce their likelihood or proactive measures to encourage prevents this situation;

- Unsettled ownership, which is sometimes caused by public entities, speculative businesses that involve cultural heritage assets, and an inappropriate use and absence of maintenance. The predominance of economic interests above the protection of heritage and the installed confusion of a vision of heritage to safeguard only as an economic resource produces speculative activity that subjugates the heritage to those interests;

- Changes or inappropriate interventions associated with watercourses or deforestation that does not include an adequate assessment of soil and flow rates, which contributes to floods and landslides.

- Lack of resources and appropriate actions by the institutions responsible for the education of built heritage for citizens who contribute to the medium- and long-term protection, understanding, dissemination and higher level of knowledge about the heritage.

- Negative impact of tourism due to a lack of regulations and strategic and proactive plans to prevent changes in the character of the historic centre while overestimating the scene;

- Effect of globalisation on the authenticity and integrity of the historic centre;

- Lack of proper planning and standards and appropriate plans for building conservation management to support measures or benefits in terms of taxes;

- Lack of technical support agencies responsible for the promotion and implementation of maintenance and conservation plans;

- Lack of financial resources for the maintenance of buildings, an imbalance in the availability of funds or inadequate rules and inaccessibility to owners for the use of funds;

- Lack of knowledge about ancient building techniques for application in the practice of rehabilitation and conservation. Lack of knowledge and preparation in terms of construction companies that generally low skill for activities of this type. An equal resistance to the recognition that the practice of conservation and rehabilitation requires expertise, specific practical training and years of experience;

- Intervention in the built heritage with inadequate measures for the conservation, rehabilitation, repair, and adaptation, which highlights the lack of technical and scientific training in the different levels of intervention. The intrusiveness levels remain high with the consequent loss of cultural value. Lack of control of interventions and properly prepared technical staff to coordinate the work.

- Introduction of reinforced concrete in the old or new materials that compromise the integrity, authenticity and durability of these ancient buildings, alteration, the former built to visually and physically compromising its integrity;

- Interventions that only maintain the front façade of the old buildings (*fachadismo*) with catastrophic effects by relegating heritage to a showcase, void of its architectural and cultural meaning. Historic centres of small towns that are not inscribed on the list of cultural heritage are unprotected: they lose authenticity and individuality and are confronted with the precarious situation of evolving into ‘new’ towns without specific character;

- The Law on State Protection of Cultural Heritage is insufficient for addressing the current market-based economy—its sanctions are symbolic and a lack of preventative measures is evident. In addition, operations that are not properly controlled and continuously ranging progressively decrease the cultural value of buildings and their authenticity and the durability of the buildings or changed components;

- Lack of maintenance actions and insufficient conservation of old buildings facilitates the occurrence and continuing degradation of its materials and structures and gradually undermines the image of the historic centre;

- Many buildings for which the ownership changes or lack of owners does not receive appropriate maintenance and care—deterioration is unimpeded and possibly promoted via a process of ongoing neglect. The problem becomes more acute when the buildings are predominantly timber or earthen buildings. An impact of the change of ownership and function in many of the old buildings in towns was an increase in building reconstruction, which resulted in the disappearance of authentic structural details (for example, window frames, doors, handrails of stairs, an roofing). Interiors, including original floor plans, silhouettes of buildings and attics were altered;

- Lack of adequate policies aimed at maintaining the built heritage, including the absence of a motivational system with regard to the investment in heritage buildings via the reduction of taxes or other incentives;

- Heritage research work has also decreased as State support is minimal and less attention is received by relevant protection institutions; as is frequently the case, owners or enterprises are reluctant to finance research projects. Inadequate or insufficient investigation and research prior to repair or interventions have resulted in the loss of several authentic construction elements including polychromatic decor.

- Floods with long-term consequences, particularly in terms of soil saturation and soil reduction, increase moisture by capillary action with degradation of the wall material and coatings that involving the effect of salt, which changes the material structure and increases the degradation of the building;

- Climate change impact;

- Pressure of permanent unemployment, combined with economically weakened inhabitants who do not have knowledge or funding to support the maintenance of their houses.

2.10.2.3. Risk causes of loss of cultural value in the agro-industrial environment

The agro-industrial environment and the major industries of the nineteenth century and early twentieth century have a common problem associated with the transmission of property and the loss of derivative function of changes in the national and international market, which caused abandonment for several years and a significant deterioration. The recovery of these structures, of which some have a significant impact on the landscape and are extremely relevant to the history of national and international industries, requires substantial investments that owners and governing institutions do not always provide. Other common problems are as follows:

- Lack of specific plans for recovery with cultural and economic sustainability and appropriated strategies;

- Inadequate development with the allocation of areas for incompatible functions, including development projects that disregard the original settlement matrix;

- Effect of globalisation that produces changes in the social structure of these regions;

- Loss of activity, namely, traditional practices;

- In other cases, the gap in these agro-industrial areas of major decision-making centres of commerce and business favoured the desertification of these areas by the continuous unbalance of population distribution in the territory. This aspect substantially hinders not only the maintenance of populations but also the preservation of its buildings;

- Modernisation of building structures without consideration of the cultural value and other alternatives that would not compromise their integrity. Irreversible changes in rural and industrial construction substantially alter the character of these sites, with a particular risk for wooden structures and earthen constructions, which comprise more structures than residential buildings;

- Decay and demolition of a building.

- Inappropriate use of water resources and favouring actions that degrade or erode soil;

The recognition of heritage areas at risk has been emphasised in the Granada Appeal (1977 pp228-9) on rural architecture to understanding that the heritage was threatened and conclude that its disappearance would be an irreparable loss. It is indicated as the main problem: the distortion of the environment due to the industrial development of agriculture and the rural exodus. Two factors are noteworthy: a) the appropriation of abandoned buildings by the city population that mischaracterises with changes to the character and b) proliferation of new buildings, which are used as a second residence, that are designed with disregard to traditions. These phenomena contribute to the demise of the local culture prior to the demise of the dominant culture in our industrial society and the impoverishment of cultural heritage. In this context, some peasants alter or destroy their homes to replace them with urban models. In addition, poorly designed industrial buildings can also profoundly change the character of a landscape. A disproportionate promotion of tourism causes profound disturbances in rural life and a general degradation of the local environment. However, the lack of specific plans to establish guidelines for intervention and compatible functions to the place is a main cause of loss of cultural values.

2.10.2.4. Risk causes of loss of cultural value of the vernacular architecture

The position of the vernacular architecture regarding the preservation of cultural value is well established in some European regions with the involvement of government or regional authorities. Other regions continue to experience a lack of recognition of its valuable meaning and remain vulnerable to disappearance by demolition. Frequent reports and alerts from National ICOMOS expose the risk of loss of this heritage, especially associated with indigenous population or natural material constructions with greater vulnerability to decay actions for lack of maintenance. Other causes listed in these reports are as follows:

- Demolition of the vernacular built for new stocks of construction in the central area or for reconstruction according to the "lines" of the vernacular heritage. Unauthorised demolitions;

- Destruction by fire (deliberately or accidentally by homeless) and lack of access to vacant or abandoned buildings barriers is a cause associated with this problem;

- Loss of original function and non-existent cultural property-management mechanisms;

- Migration of part of the population;

- *Fachadismo* (maintenance only of the facades of the building), using the remains of the old building as a theatre setup, reducing to nothing its cultural value, leaving only parts of this setup, which prevents a complete reading of it, for lack of strategies and legislation to ensure their protection;

- The desire to replace ‘the old and simple’, the differences begin to disappear. Simplification in production, urged by economic pressure, directly results in the disappearance of ancient building typologies and respective construction systems.

- Unclear responsibilities that are divided across too many administrative instances have resulted in the absence of controls, sanctions and proactive measures. The cost of projects, materials and work and the excessive number of necessary authorisations should be considered. This consideration make it impossible for owners on a low income or a pension, who are willing to maintain their older house in a respectful manner, to conduct on maintenance, repair or conservation work. In some countries, the taxes applied to rehabilitation intervention discourage the will to repair and decreases the residential rental market;

- Infrastructure building with a significant impact on the built form, level of traffic and pollution;

- Banks and other enterprises (some associated with tourism and hotels) are building new facilities without concern for the architecture or character of the surroundings;

- Actions of climate effects that are not being repaired over time and cause the loss of the building by decay integrity;

- Difficulty in obtaining natural materials those are suitable/compatible with remedial actions and conservation/rehabilitation. In this respect, we can also include the lack of planning and forest management, which would provide a stock of wood species that are identical to the stock applied in the old buildings;

- Loss of traditional building practices with a consequent loss of maintaining acceptable levels of authenticity and the introduction of new materials, which can be physically inadequate or chemically incompatible;

- Legislation and inadequate regulation for the conservation of vernacular architecture. Lack of guidelines of conservation or rehabilitation interventions, which can favour the maintenance of high levels of authenticity of vernacular heritage;

- Effective studies of historic building types and the related cultural patterns, including multicultural links;

- "Modernisation" of the vernacular built with a strong negative impact on authenticity and integrity. High standardisation subdued to business models and production, which eradicate the traditional practices of construction and a manufacture of their particular elements;

- Problems in the transfer of ownership, which frequently results in the loss of function of vernacular buildings and their maintenance. Lack of adequate maintenance know-how for traditional construction;

- Use of vernacular structures for tourism with a negative impact due to a lack of appropriate criteria for intervention that enhances the facade of the scenario at the expense of everything else.

- Lifestyle changes among the majority of the population and the prevailing indifference and disregard for the country's physical heritage suggests that only minority populations are interested in its preservation. This misconception can be partly attributed to a lack of public awareness concerning the importance of many aspects of the country's heritage. This outcome is a failure of the education on heritage protection for students, without proper and sufficient education initiatives. The official support for this area remains fragmented and weak without a long-term well-planned program.

- The large number of daily constructions is achieved without architects and a large percentage of buildings are constructed without administrative permission. The result is a transformation of the cultural landscape into a chaos of private aesthetics, without any sense of the entire urban area as the construction of the future heritage place.

- Incorrect interventions that spoil the original masonry by substituting the original support construction elements;

- Professionals in the current conservation/rehabilitation fields would rather focus on science than confront changes in society. The valid arguments that can make a significant difference in the protection and preservation of this heritage rather than only expect insufficient results from prohibitions of regulations;

- Selling materials from abandoned buildings;

- Replace traditional materials with industrial substitutes.

2.10.2.5. Risk causes of loss of cultural value of the Modern Movement architecture

The interest in recognising that the Modern Movement architecture is the great recent or future Heritage has grown throughout Europe and America and currently presents interesting debates about the most appropriate processes of rehabilitation. Despite this starting point, which began almost ten years ago in some countries, it is a heritage that is struggling to be recognised as such in many others. One difficulty relates to the fact that many of the materials, such as the reinforced concrete, are common in current construction. For this reason, both material and construction techniques are difficult to assess in terms of what must be preserved and many of these structures have severe pathologies that involve reinforced concrete and infiltration by inefficient tightness in coverage. The rehabilitation and renovation of buildings raises the question of what can be understood as maintenance of its authenticity and integrity.

For the previously identified sectors of Heritage (monumental or vernacular), these concepts can be understand. In the case of Modern Movement buildings, this situation is based on the design conception of an author and the consistency of the maintenance of these intentions. That is, cannot be reduced only to the evaluation of the existing building, but should involve the analysis of the unique design (role on the history of an authorship or architecture) with their written documents and design plans to clarify and guide the best intervention proposal by other following technicians. This same understanding of building design base is also patent for the examples buildings of Art Nouveau and Art Deco, which high decorative characteristics seems to favour an easily recognition of their cultural value. Interestingly, it can be seen that in the public opinion and in the decision-making entities opinion, there is this trend of greater cultural value recognition facility to buildings with more decorative feature. This aspect can lead us to equate the like in the near future generations will understand/recognise the Modern Movement Heritage protection, especially in the cases of absence of decoration. Is this "defect" of understanding or "taste education" that supports the current lack of recognition of Modernist buildings in some countries?

Of the indications noted in some international reports are to relieve the following problems to maintain the cultural value of Modernist buildings:

- Need for research that supports the conservation and rehabilitation processes due to a recurring problem of the durability of some of the materials and the transmission of this research to the practice of repair and rehabilitation;

- Total or partial demolition;

- Lack of legal protection;

- Changes or elimination of significant elements of the building, loss of their morphological coherence due to consecutive additions and substitutions;

- Lack of understanding/awareness of the cultural values of this heritage;

- Urban pressure and development;

- Uniform application of pressure building codes;

- Culture where it is considered more profitable to build new constructions than to preserve. Consequently, there is an extinction of fundamental architectonical pieces which diminish the comprehension of the modern city. ;

- Lack of regular maintenance actions;

- Decay.

2.11. The case study of Portuguese adobe construction

In Portugal, the adobe construction is still present in many of the city centres of the Central Region of Portugal (Figure 2-17), along the coast, being the branch image of these places, as in urban or rural areas. With a lower incidence it is also present more to the south in Alentejo region and Algarve and to the North. Despite the division by the mountains of the Interior Central region of Portugal, it is observed the existence of adobe construction also in the Central region of Spain and in several other regions in European countries.

Contrary to what is noted by some researchers, adobe construction was not only used in rural settlements or for poor dwellings. There are even currently adobe buildings for all type of functions, from rich construction to very simple dwellings. A special emphasises was made to residential buildings, as it is the predominant function of the existent buildings.

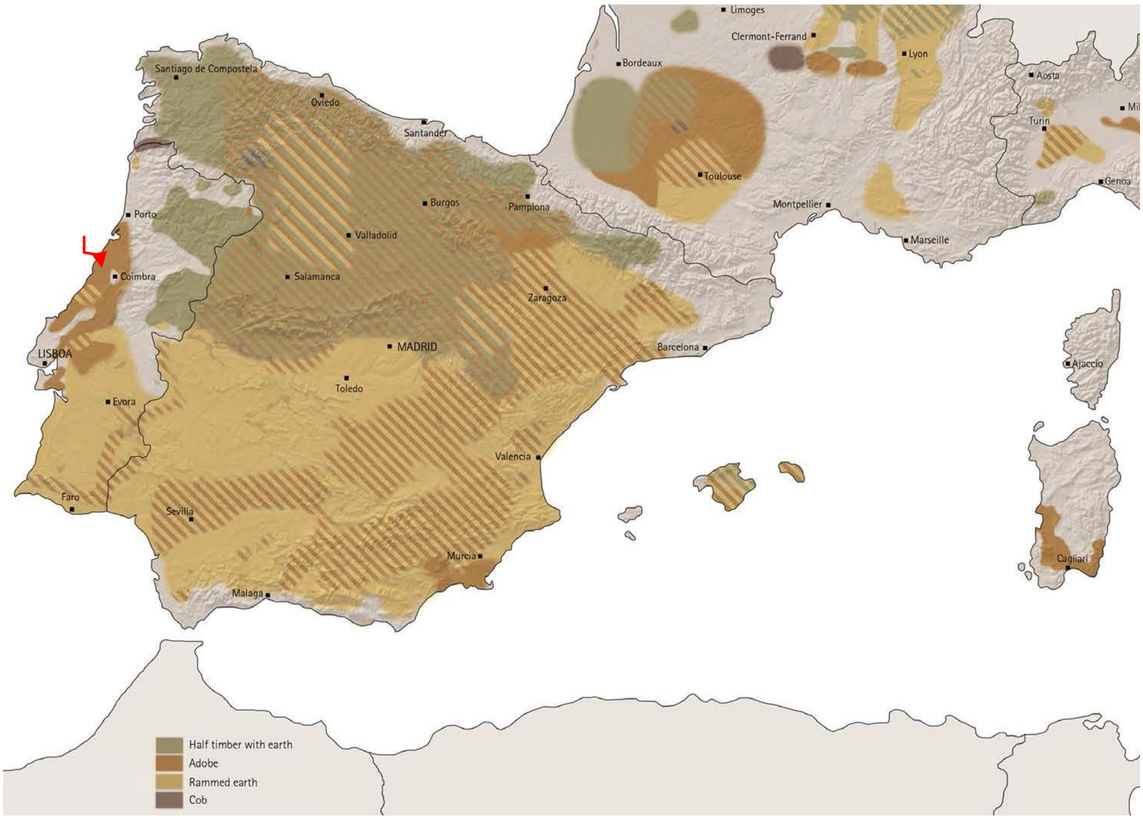

Figure 2-17 - European map identifying earthen construction Iberian region. In Terra Incognita, 2008.

In the restoration of vernacular architecture, inappropriately adopted solutions, such as irreversible structural changes or repairing renderings with cement mortars, are not uncommon. As was discussed, the concerns on the compatibility between materials and the definition of adequate components were already presented as main issues in ancient treatises. Specific recommendations were made for aspects related to the structural safety of the constructions, putting the emphasis on the information captured from the observation of ancient buildings contributing for the better establishment of the durability requirements. Particularly, the connections of the construction elements (wall-to-wall, wall-to-floors, wall-to-roof) were issues discussed in several treatises as well in the engineered proposals of the 18th century, considering special rules on seismic prone regions. These concerns, in vernacular construction, can be observed in the foundations, corners, distance between openings (doors and windows), as well as in the choice of the materials and in the definition of the construction geometry.

Nevertheless, the substantial and progressive decrease of this type of construction system in the present shows the urgent need to address the causes of threat and compare with the other cases of traditional construction systems. The understanding in which terms the adobe construction system should be recognised as a multicultural value, in terms of traditional technique shared by many regions and societies is another motivation of the following study. This will be presented in detail in its various aspects, including its links with the current architecture movements. The characteristics recognised both in thermal and acoustic shed for adobe are sufficient reasons for the recovery of this technique, which reveals the known sustainable characteristics. However, for the establishment of strategies in this direction we need to check what factors contributed in the recent past for its disappearance as a living technique in Europe. From the general issues noted in the synthesis of the problems analysed it was considered that present close links with the characterisation of the specific threat situation for adobe construction system. For this reason, the final comments will emphasise the major causes that better fits for this characterisation.

Although the recognition of the cultural value of adobe constructions needs further awareness and research to be successful, there are other general very relevant aspects to address:

- lack of a national regulation for Conservation and Rehabilitation. From this situation can be noted two negative effects: lack of awareness of the population about authenticity and integrity values and an increased number of *ad hoc* solutions with negative impact;

- crises in the rental residential market. More than ten years of restriction laws that imposed to holders reduced and frozen rents led to the disappearing of regular maintenance measures. In a consequence the old buildings were in progressive decay with inhabitants elder or with less resources leading to the desertification of the urban centres. In the present it is observed the impoverishment of the owners and their more vulnerable position to surpass the economic crisis, the increasing of urban taxes which is leading in some cases to the only action that they can afford: the demolition of their own properties. In addition, the action to revitalise the urban centres are not taking in account the huge social support that these owners were obliged to do (which was a responsibility of the State) and expropriation is used to substitute the ownership of the properties.

- the increasing number of network platforms involving universities, enterprises, organisations, and builders to support and enforce the rehabilitation in the country presents several times a huge gap in strategic terms of cultural protection of the heritage that is not under supervision of public bodies (not monumental). Although all the efforts in combining research with the application in the field through the building companies, industries and universities, there is the risk of again, a lost opportunity for balanced development strategies. This can be seen through the planning ideas that these platforms published or communicated in conferences – many expected scientific advances; many experts involved; but non communication about the strategy, planning or management of the expected technical-scientific advances to accomplish goals of preservation of authenticity and integrity of the ancient buildings or at least the compatibility with that goals. Cultural protection bodies in these networks or the promotion of an open debate about the conservation or rehabilitation philosophy that will be prosecuted is needed. The lack of these essential demands will cause the loss of the built heritage, which is greater than the long-process decay. The combination of inadequate legislation and construction regulations, some of which are incompatible with correct conservation or rehabilitation strategies (able to protect the cultural value of the building), and the role of some of these network platforms will impose the loss of heritage to future generations.

2.12.Final Comments

The debate about the interaction between the understandings of the particular character of traditional construction versus the extensive range of available techniques requires an exigent and accurate sense of intervention strategy.

The lack of knowledge about traditional construction systems, the difficulty of controlling their structural performance and the exact characterisation of their state of conservation must not be an obstacle to their preservation. This notion implies that significant background knowledge about multidisciplinary approaches for interventions in vernacular construction systems is necessary. The compatibility of definitions, the knowledge achieved from written ancient sources, and the identification and understanding of the links of culture or techniques exchange are relevant issues to include in the study of traditional construction techniques. The link between the evolution of European traditional construction and the Asian antique construction is recognisable, namely, construction involving mixed systems with timber structures. The comparative study of some historic and vernacular construction systems from different seismic prone regions shows the relevance of the construction to the connections between perpendicular walls to improve the global capacity. This area of research needs further development, especially with regard to seismic resilience. The ancient documental resources are a highly valuable issue to include in the analyses of ancient constructions systems. Although existing buildings are a main resource of information, the multicultural missing link can be achieved in many of the treatises and books of practices. This study noted an example—the solution for the corners—that is transversal to many cultures and demonstrates the awareness that the same construction limitation can generate a similar solution. An understanding of some of the main differences in the categories of the construction systems and the specific characteristics of the old solutions is necessary. This knowledge is also the basis for understanding why traditional construction systems do not have the same roles as current technological solutions: they belong to a different field. Although the adobe construction system is evident in almost all continents, the difficulties in its protection are similar to the challenges of traditional mixed systems with timber or stone masonry.

The causes that are responsible for the loss of traditional heritage were analysed using ICOMOS reports of more than 35 countries, which correspond to the period between 2000 and 2014. It was given special attention in the sectors of monumental and public buildings, historic urban centres, agro-industrial settlements, vernacular architecture and the new heritage of Modern Movement buildings. Adobe construction was applied in these main sectors despite their relation to Modernist buildings, which were primarily observed in the first stage of the Architectural Movement in Portugal. The problems common to other traditional construction systems in a globalised world are interesting, and the causes of a disappearing heritage should also have a broad focus.

Based on the causes discussed in subchapter 2.6—Risk of loss of cultural value—five transversal main causes can be concluded for all sectors:

1. Lack of appropriate plans and management.
2. Lack of planned education for heritage awareness and long-term protection.
3. Lack of control of investment—the measures should anticipate the stress imposed on heritage places and should be clear in terms of restrictions or incentives.
4. Insufficient technical skills at all levels regarding maintenance, conservation and rehabilitation, and planning.
5. Communication of research—increasing their link with the measures in the field and for the establishment of strategies of intervention at all levels.

In these causes, some aspects could be avoided if a proactive attitude was perceived and effective co-ordination was achieved at all levels—from the governments to regional entities and involving the owners. The inertia to take preventive actions reveals three additional problems.

a) A public opinion less developed and aware of the problems, with initiative to share the planning decisions and with capacity to pressure the political decision. Although in some cases is not allowed to do so;
b) The principle of minimal intervention is rarely promoted in the context of renovation or reconstruction procedure on existing buildings, consequently the understanding of the problem involves always a huge amount of resources that are not available.
c) Incapacity of the authorities/entities, namely politicians to prepare sustainable and adequate measures (long-term strategy) that go behind the period of their permanence in charge. This also involves a lack of evaluation of the present situation, the monitoring of the programs for attempted correction measures and a better distribution of resources.

Finally, it should be emphasized that was also several times identified problems in the conservationist approach, for the preservation of the authenticity the work not always is undertaken by adequately trained personnel. The same with respect to companies and contractors working in conservation projects, that not include technical staff, adequately trained to act as respondents for the conservation experts, as well as workers and crafts persons appropriately trained to accomplish the work. A multidisciplinary approach with people from different backgrounds is an adequate approach; however clustered actions lead to negative results, in particular when cultural heritage is used as an opportunistic resource.

At least three key reasons to study traditional construction techniques today can be addressed by researchers to help the protection of the cultural value:

- To give accurate guidelines for the Protection and preservation of this heritage based on research and laboratory tests, increasing the communication of his knowledge to technicians who work in the field;

- Dissemination of the knowledge that supports multicultural values awareness based on an understanding of the links between traditional construction methods (which can lead to an interesting debate on identity);

- To propose guidelines for adequate maintenance measures, compatible interventions in terms of materials, techniques (conservation or rehabilitation) and strategies that can guarantee the future use of buildings with high cultural value.

3. TRADITIONAL CONSTRUCTIONS SYSTEMS AND THE ADOBE CASE

3.1. Introduction

Earthen architecture research has been developed in Portugal by several researchers (Aníbal Costa, Humberto Varum, Mariana Correia, Maria Fernandes, Dora Silveira). The University of Aveiro's (Department of Civil Engineering) research on the characterization of adobe architecture in the Aveiro region and the mechanical characteristics of the adobe construction system should be highlighted. This university, in collaboration with other institutions, such as municipalities, has systematically produced several documents that can promote guidelines that aim to protect and rehabilitate this heritage.

The work presented herein assumes that the construction system is a key issue in the protection of vernacular and civil architecture. To culturally value and preserve the adobe construction system, deeper knowledge of the following issues is needed:

- characterization of the construction system – the most commonly implemented solutions and the system's variations across time;

- identification and understanding of the processes that influenced the evolution of the construction system – which regional, national or international influences took place in terms of expertise, workmanship, industrial production, construction methods, materials availability and trade, new techniques and materials arrival, regulations and legislations;

- understanding of the interaction between architecture and engineering in the common field of the construction system;

- identification of the factors that led to the disappearance of the construction system.

The current research focuses specifically on the adobe construction but also takes into consideration the influence of other construction systems. We first recognized that the main threat to the adobe architecture was the systematic and widespread implementation of demolition decisions based on the argument of structural defects and the high level of decay of the construction (Tavares A et al. 2012a).

However, the preliminary *in situ* assessment revealed that this situation came from: (i) lack of regulations specific to adobe construction, (ii) lack of technical knowledge regarding this construction system and (iii) lack of recognition of the cultural value of this ancestral technique, which is otherwise spread worldwide. In reality the lack of specific protection measures, results not only from the depreciation of the history of the region, but also from the increased appreciation of a globalized and assumed “updated” world or possibly also due to presupposition of less structure durability of the traditional construction system.

This chapter includes the case study of the adobe construction system of a representative region, where all the stages of the evolution of the construction system can be observed, from the traditional building strategies until the introduction of the reinforced concrete in the system.

The selected area is in the coastal Central region of Portugal (Aveiro district – a 2.808 Km^2 region, with presently more than 735.790 inhabitants and nineteen municipalities), where this system was more deeply present in the traditional way of built. Presently, the existent adobe buildings of this region (Figure 3-18) belong to the 19^{th} and 20^{th}-centuries. Therefore, the study was based mostly on the construction typologies from this period.

Figure 3-18 – Geographic location of Ílhavo county – study area [Photo by Nuno Marques]

In addition, a preliminary research (Tavares A. 2009, Tavares et al. 2010-2014) allowed the assessment of the Portugal Northen region (Porto district) influence on the adobe construction system evolution. Although Porto has stone masonry as the base of its antique construction system, its influence in Aveiro district can be addressed in terms of construction agents, technicians, industries, timber market and its application in the construction through the implementation of some roof typologies and others.

In order to fulfil the proposed objective, buildings from the 1895-1956 periods were assessed and more than 2379 architectural and contract files of the Aveiro district archives were analysed, from these only 725 processes were validated. These archive files include different levels of information and originally they were used to obtain the building municipal approval.

Also, to produce a comparison base and the understanding of the Northen regional influence, more than 1462 architectural processes from the Porto archive, were analysed from which 998 archive files were validated. Porto archive has more complete ancient files than Aveiro archives, allowing to understand which materials or techniques were adopted and could influenced surrounding regions.

The archive files selection was based on mandatory criteria of precise written information about the specific materials applied to the different construction components as well as the dimension of the elements. Therefore, all archive files with references of "usual sections" or "regional materials", were not included in the database of this research. There were cases where the archive file had incomplete information on same topics but validated information on other sections. In these cases only the validated information was assumed.

To sum up, 1723 were the total archive files used and considered in this research constituting a relevant and representative database. Furthermore, the *in situ* surveys were crucial to complete and understand the full characterization of some variations of the construction system presented in the archive files.

In relation to periods previous to the 20^{th}-century, the *in situ* surveys were mostly of big houses/small palaces and a few churches or chapels, so the description of the construction system should be understood taking this in consideration, since it was not possible so far to further assess identical number of small dwellings of the same period and the study is still in progress.

Finally, this chapter includes subchapters with specific information details of building components - foundation, walls, floors structure and roof structure – for a better understanding of the adobe construction system. In the end of each subchapters, resume tables can be found. They include a synthesis of the common values characterizing each component of the construction.

3.2. Evolution of adobe construction system (19^{th} until 20^{th} century)

The existing buildings of the 19^{th} and 20^{th}-centuries had all the kind of functions, such as housing, schools, factories, churches, warehouses, wells, etc. They were not associated to a specific social class or function, which reveal its great scope and contradict several common assumptions stated by some researchers that associate them to poor people with fewer resources (Figure 3-19). In opposition, the system history shows an impressive way of adaptation to regional environment, traditional activities with a very practical sense of using the local available resources.

Figure 3-19 – Sample of typologies of buildings of the study [credits Alice Tavares]

The *in situ* surveys shows that in this region (Aveiro district), and previous to the 19^{th}-century, alongside to the adobe construction there were a rammed earth with stones and (Figure 3-20) earth mortar infill (denomination adopted from Terra Europae, 2011) construction system with a mix of materials, small rocks, tiles and scrolled stones. This masonry was adopted several times in the exterior loadbearing walls. When used simultaneously with adobe, the stone masonry is frequently found on basement and foundations (commonly using red sandstone of the region, known as *Pedra de Eirol* or scrolled stones from the ships). This earthen masonry with stones can be built until the first floor with frequently more than 1.0 m thickness, and usually no more than two floors building with an attic are observed. Nevertheless, the use of stone masonry can also be seen until the first floor with similar thickness. The adobe was used for the upper floors and also in the interior, including some loadbearing walls for the space division.

In small palaces of the 19^{th} (or even 18^{th}) with adobe masonry it is present a similar situation with sandstone masonry and earthen mortar on the foundations. Some of them used a loadbearing wall along the middle of the construction with 10.0 m width or more, occasionally using arches of brick or adobe in this wall (Figure 3-21, Figure 3-22). In the end of the 19th- century it was possible to find iron beams in this position of the construction with the same objective of reducing the span to support the structure of the floors. The timber structure of the floors was usually made of regularly spaced round timber beams, frequently with 0.20-0.25 m diameter, above which were placed the timber floorboards.

In these ancient buildings the roof structure was also made with round timber beams, usually a purlins truss or a rafter truss with struts as additional support to reduce the span (Tavares A et al. 2013). The timber elements were mostly uncut pieces that oblige the use of (manufactured) nails with 1 cm thickness, connecting the rafter to the strut or to the partition wall (*tabique* wall – half-timbered with earth plaster). The use of such simple roof structure solutions is in accordance with a less industrial development of the region in terms of the timber industry at the time, as will be further analysed in following subchapter. For this reason, the structures had less cuts and manufactured details and could be built in a few months. Thicker adobe walls, sometimes up to double in size, than those of the middle of the 20th-century are also found in older construction.

Figure 3-20 – Earthen masonry with stones [credits Alice Tavares]

Figure 3-21 – Ground floor Wall with stone masonry and brick arches [credits Alice Tavares]

Figure 3-22 – Void space of ventilation at the level of basement/foundations [credits Alice Tavares]

Thus, the buildings from the 20th-century period distinguish from the previous period, through the specific materials used, their distribution in the construction, thickness of the walls and roof structure typologies and the expected architectural differences. Besides these adobe constructions with characteristics similar to the presently established, it was also found solutions with links with Southern region, identified by the use of limestone elements in the front facade. Nevertheless, the Southern influence of the 18th and beginning of 19th centuries will lose space to the Northern influence until the end of the 19th century.

As time passed by, from 1910's to 1940's, the height of the floors in common dwellings was decreasing accompanied by a thinner thickness of the walls. As we could assess this situation was linked with regulatory changes in the urban settlement. This imposed the need to improve a functional construction system, which in addition with architectural conceptual ideas of international influence, and changes in lifestyle caused some consecutively variations on the adobe construction system particularly after 1930s until 1950s. In terms of construction, this transition period was characterised by the prescription of reinforced concrete by designers and builders for specific areas of the adobe construction. Almost in the same areas where previously were used layers or arches of bricks as in the lintels of the openings, with the rational of strengthen those parts of the construction and improve its durability. However, in most situations the idea of resilient walls remained, which was also adopted when changed adobe for brick in the middle of 20th century. Despite pressure from the ceramic and cement industries felt during this period, the adobe system remained implemented. Therefore, the role of the industries in this process of evolution must be assessed. One of such industries and particularly relevant for the region, is the Porcelain Factory of Vista Alegre (VA factory – Figure 3-23). This factory is in production since the 19th century in Ílhavo, and it was one of the most developed industries of the region with a specific technical team of engineers and designers that controlled the construction and maintenance of the building stock of VA (Tavares A. et al. 2010-b). They adopted the adobe in their new buildings, controlling all the process of construction, and obliged the contractor to submit all materials for inspection and approval prior to construction. This factory was responsible to supply the adobes blocks, the used timber and some other materials, including recycled materials, for the new buildings, enlargements or repairs. The use of reinforced concrete was also adopted by them.

Figure 3-23 – Housing from different development phases of the Working Neighborhood of the Porcelain

Factory of Vista Alegre [credits Alice Tavares]

The introduction of reinforced concrete elements in adobe construction was gradual (Tavares A et al. 2011-a). Nevertheless in the 1940's these variations coexisted simultaneously. It was identified four main types of use, implemented as following:

1º - RgB – use of thinner ring beams commonly around all the construction;

2º - RgB/S – use of ring beams and a few slabs;

3º - RgB/S/P – use of ring beams, slabs and isolated pillars;

4º - PORT/S – use of a system with pillars and beams as the main structural element of the construction.

The several introduction phases of reinforced concrete were adopted initially on non-residential construction (mostly in industrial buildings) and only some years later they were progressively integrated in dwellings.

These changes illustrate the evolution of the adobe construction system and they will be further explained on the followings subchapters. The traditional construction system will be identified as Solution T (Figure 3-24), the others solutions, the mixed solutions with adobe and reinforced concrete elements will be identified respectively as RgB, RgB/S, RgB/S/P (Figure 3-25, Figure 3-26).

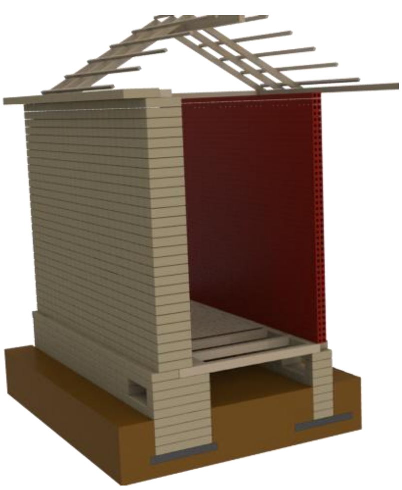

Figure 3-24 – Traditional adobe system construction (Solution T) [credits Alice Tavares]

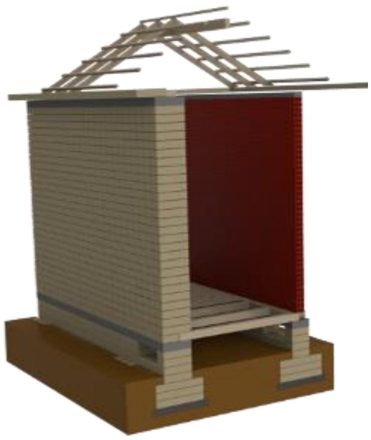

Figure 3-25 – Solution RgB [credits Alice Tavares]

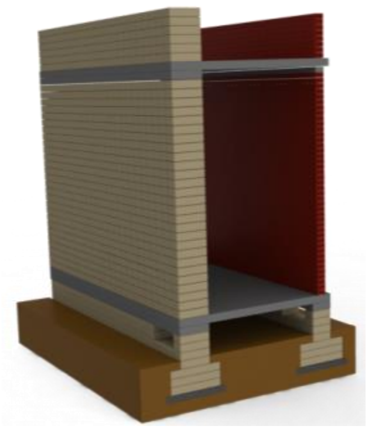

Figure 3-26 – Other types of adobe construction system with RC [credits Alice Tavares]

3.2.1. The influence of laws and regulations in the construction evolution

Some of the changes on the traditional construction system were imposed by changes in the legislation and by municipal regulations. The national legislation almost did not mention the adobe construction and oblige this type of construction to fulfil the same criteria as for other construction systems. This, in some cases introduced some vulnerability to the adobe construction system as will be explained later. A few exceptions (1903 and 1951 national Regulations) gave authorization to Municipal Councils to approve specific guidelines for the traditional construction systems of their jurisdiction.

Thus, it should be considered the legislation impact on the concept of private property, health care, fire, lighting, ventilation, urbanism, industrial materials/ reinforced concrete, because all of them had an impact on the traditional construction.

The Portuguese Penal Code of 1852 established the basis of health-related requirements in construction procedures in the urban context. This code included four articles related to public health rules and conceived for the first time the public health as a legal issue to defend (Cosme J. 2006, p.182). In Europe, urban life conditions and its links with the type of construction or urban plans (in industrial places for instance) was central to political debate. This was expressed in England, in 1845, by Friedrich Engels (Engels F 1845) through the publication about life conditions of proletarian workers. However, progress in this field in Europe was not the same in all countries. In France (Paris) the construction of large residential blocks with 5-6 floors (1852- 1870) was accompanied by legislation that limited the height of the buildings. This issue would be present in future urban regulations. During the 19th century epidemic risks, infections, fire risks and industrial growth effects were the drivers for the debate on housing conditions mainly, health-related issues, and water supply system and garbage removal. Again, in 1832 Europe had to deal with epidemics, as the deadly cholera brought from India that quickly expanded to Europe through the international trade with England (Viegas V. et al. 2006, p.7). Although Portugal forbidden the entrance of English ships in Portuguese seaports, in 1833 the arrival of the London merchant ship with 200 Belgian soldiers brought cholera with them to Porto. Cholera was quickly disseminated to Aveiro and a few months later to Lisbon (Viegas V. et al. 2006, p.8). This event exposed the deficiencies in terms of public health particularly control of epidemics, but also of insufficiencies on the urban regulations. New urban plans and architectural rules were introduced in the regulations to control the negative health effects of existing housing conditions in industrial regions. The 1842 Portuguese Administrative code established preliminary public health and urban requirements in its article 120, to be included in future municipality regulations. The debate on construction in Portugal improved the implementation of new rules (*Diário do Governo*, nº 211, 7th of September of 1855) for industrial structures and their impact on the nearby residential areas. Later on, the 1864 administrative code established rules to be implemented by the municipalities which included the proportions between height of buildings and width of the streets, following other European countries indications, the height of interior spaces set at no less than 3.0 m (art.36), and also the imposition of previous approval of the architectural design plans (Tavares A et al. 2012-b). In Lisbon, the General Plan of Improvement of Lisbon established the height of buildings concerning each width of the streets (Decree-Law of 31th of December of 1864). In Portugal the population growth in the city centre of major cities as Porto due industrial activities, as in between 1864 and 1890, also triggered the need of new measures. Lisbon and Porto, the two principal cities of Portugal, were used as an example to be followed by the rest of the municipalities; this is the reason of specific laws and the basis for future regional influence.

The General Plan of improvements of the towns and villages of the Kingdom (*Plano Geral de Melhoramentos das Cidades e Vilas do Reino*) of 31th December of 1864 applied in Portugal, but also in the Portuguese colonies (ex: Macau – Afonso J. 1998) had a relevant impact in the urbanisation of later decades. This was a Decree Law which anticipated several equivalent legislation in Europe, namely in Sweden (1874), Netherlands (1901), England and France (1909) (Afonso J. 1998). The following administrative codes of 1878 and 1896 also presented the need of new rules to implement by the municipalities in the fields of public health and urban regulations. The compatibility between urban development and public health was an issue in continuous debate. Again, in Portugal, the occurrence of the cholera epidemic in 1894 in Lisbon (the capital) and the bubonic plague in 1899 in Porto (Figure 3-27) represented two strong reasons to act again in two issues: public health and urban living conditions. This resumed on the publication of the following legislation of 14th February 1903, the law decree "Regulation of Salubrity of Urban buildings" (*Regulamento de salubridade da edificação urbana – RSEU 1903*).

Figure 3-27 – Photo of Porto during the bubonic plague by Guedes, 1899. Credits: Municipal Archive Porto

In addition to the balanced urban development, other public health criteria were included as well as fire security rules. In this period, issues related with ventilation and natural light were also present in the legislation and discussed in newspapers and specialized magazines. So, it is noted that some of the changes in the construction system occurred under the influence or imposition of laws or regulations with international influences, urging its comparison with the national guidelines. Namely the regulations regarding land development plans, with specific rules for the building alignment, width, height and depth of the buildings. It should be pointed out some of the rules with impact on structural behaviour of the construction:

- soil drainage, when needed, before any construction;

- walls foundations must be made of waterproof materials or be covered by them;

- maximum buildings height limited to 20.0 m (not including public buildings);

- minimum height for each floor – ground floor, 3.25 m; first floor, 3.25 m; second floor, 3.00 m; third floor, 2.85 m; fourth and fifth floors, 2.75 m;

- obliged to the floors waterproofing with a ventilation void on the construction basement of 0.60 m height;

- lightening and ventilation of stair well;

- minimal area of the openings of 1/10 of the area of the room;

- sanitary issues, between others.

These modifications introduced by the regulations (national or municipal and along the 20th century) imposed changes in the thickness of the walls. A sensitive issue concerning adobe constructions, given the balance between the thickness and the height of the wall, which could led to new vulnerabilities. For this reason, the strengthening of the connection of the walls and the use of some complementary metal devices were important to achieve a better structural stability. Some materials conditions for mortars and plaster were impose, along with some maintenance measures.

The 1903's regulation imposed the obligation of architectural design approvals from the Town Council previous of beginning of any construction, increasing the requirements of written and design elements to clarify the proposed solution. This regulation was restricted to the principal regions of Porto and Lisbon. This fact justifies the continous and spontaneous construction (eventually, vernacular) with less technical control by town Councils in other regions as Ílhavo. Neverthess, this regulation influenced Ílhavo to increasingly control the implementation of new urban interventions. So, the construction traditional systems continue to have a more persistent and prominent impact than the technical engineered influence. The 58th article of 1903 Regulation is also interesting because established that the Town Council could grant the use of a newly constructed building only two months after its conclusion, in summer and, three months in winter. This could be interpreted as an attempt to protect users against early failure due to construction defects (Tavares A. et al. 2012-b). This regulation already impacted the construction, however, the traditional practices continued for the most new dwellings in the area of the case study (Aveiro district). The Regulation of the Art and Architecture Council of 1929 introduced additional impositions regarding the requirements needed for previous approval, including more detailed information about the foundations. On the other hand, the introduction of the obligation of implementation of General Plans of Urbanisation (*Planos Gerais de Urbanização*) in 1934 (Law decree nº 24 802 of 21 December 1934) start a new challenge for the traditional types of construction. This legislation was applied for all the municipality areas, urban nucleus with more than 2.500 inhabitants and locals with a special interest as touristic, cultural, historical, and others. Such impact was widespread with the following General Plans of Urbanisation and Expansion (*Planos Gerais de Urbanização e de Expansão*) in 1944 (Law decree 33 931 of 5th September 1944) and Preliminary Plans of Urbanisation (*Ante-Planos de Urbanização)* in 1946 (Law decree 35 931 of 4th November of 1946). These events had an impact in the construction system due to the changes in: (i) the increased metric of urban allotment; (ii) the proposals of the multifamily building height in opposition to the single family structures (despite the occupancy was not always subdued to this); (iii) in some cases, the encouragement of the use of Modernist languages of Architecture which implied in most cases different materials and techniques; (iv) the imposition of some dispositions as in terms of architectural configuration or in materials used, (e.g. use of reinforced concrete for the roof structure of non-residential buildings) and finally, (v) the growing importance of the design of architects that produced the plans, and ruled in many cases the control of its application or even the municipality technicians that sometimes imposed their ideas about materials and colours of the facades. Gradually, due to specific rules of the General Plans, municipality rules or restricted definitions imposed by these technicians, the traditional methods of construction had to adapt introducing some changes, which also involved the adaptation to the industrial market at the time.

In the beginning of the 20th century, changes in the production systems regarding construction and industry included the promotion of new materials with innovative features, which were increasingly applied since the Industrial Revolution.

Experiments in Europe and in the United States from 1850 until at least 1900 were conducted on the combination of two common materials at the time, cement and industrial iron (Iori T. 2006), leading to reinforced concrete. This innovation was responsible for a wide, international discussion involving architects, civil engineers, politicians and society in general. Its dissemination through the world happened with different arrangements: in combination with traditional construction systems, as marketing of nationalism and/or even as international promotion of the countries. This led to controversial positions in the construction/technical community, enhanced by architectural conceptions and progressively engineered advances, both influencing urban relation and its image. The rapid dissemination of the reinforced concrete was not only due to its technical qualities but also supported through social networks with different actors such as building contractors, engineers, architects, financiers and politicians. Together, they created an expected trustful climate linking technology to cultural and political values (Jost H-U. 2006). The patents promoted through "marketing" campaigns were an important way of spreading technology, as with the Hennebique system in several European countries (Hennebique F. 1892; Nelva R. & Signoreli B. 1990), such as Italy (Iori T. 2006), Switzerland (Jost H-U. 2006) and Portugal (Costa A. 2012), where a series of branch agencies were set up or commercialisation allowance was given.

The interest of civil engineers in these solutions did not decrease even with some setbacks due to disasters in Basel and Bern or through the strong reluctance of some experts, such as the Professor Mirko Ros, the director of the federal laboratory of material tests (Jost H-U. 2006), who defined reinforced concrete as an unfortunate misalliance because concrete breaks, iron rusts and theory is on strike (Ros M. 1921). Additionally, the "concrete materials", according to Donghi's list included in *Manuale dell'Architetto*, were considered to have great ornamental possibilities and strong mechanical resistance but already mentioned the needed protection against atmospheric agents (Donghi 1906; Giglio A. 2006). This contradictory framework did not diminish its use, although, in some countries, it was pointed as the destructive element of the "authenticity" of the landscape. In addition, as mentioned by Jost H.-U., specifically to the situation in Switzerland (1890-1914) that only few people actually mastered the new technique and technology at that time and maintained some doubts on the reliability of the material.

Nevertheless, the technique became increasingly accessible to companies and to project designers, who quickly converted to the new technology (Iori T. 2006) instead of using the traditional methods. In Portugal, the first regulation with guidelines for the reinforced concrete is from 1918, despite the technique was being used before this date. The Decree-Law nº 4036 of 3th of April of 1918 mentions in its introduction the French guidelines for reinforced concrete of 20th October of 1906. The 1918 Decree imposed the previous need of approval of the reinforced concrete design plans, the characteristics of materials, the laboratory tests at 7 and 28 days of samples (compression and tension), included guidelines for the calculations of mechanical behaviour, as well as, the characteristics of slabs, beams and methods of construction. Moreover, this Decree-Law defined no less than 0.08 m of thickness for rigid slabs. This justifies the 0.10 m thickness disseminated in Aveiro region as in others until the following legislation concerning reinforced concrete - the Decree-Law nº 25948 of 1935. This Decree-Law mention again the French rules of 1906, but also the Belgian of 1923, the Switzerland regulation of 1915, the Italian of 1932 (but also of 1907, 1925, 1927, 1928 and 1930), the Netherlands of 1930 and finally the USA of 1924 and the German regulations of 1907, 1916, 1925 and 1932. This shows not only the knowledge about the European regulations, but also its reflexion and need to have the most recent regulations or scientific achievements in this field. It also emphasized that the reinforced concrete was being used with empiricism and audacity since the patents of Joseph Monier in 1873 and 1878. This Decree considers reinforced concrete a 20th century technique, as only at the time the increasing laboratory tests implemented allowed deeper knowledge about the matter.

The success of reinforced concrete growing application in many countries was due to: the creation of new companies specialised in its use (Iori T. 2006), new specific laws and regulations, technical support from documents, specialised journals (Collins P. 1959) and manuals with basic procedures and standards (Guidi 1901, Canevazzi 1901), to changes on the professional training of engineers due to universities that included specific information in their courses (Iori T. 2006) and to application of the technique in public buildings as well as other buildings. All of these cross conditions involved the need for improvements in various fields. The transition from old to new within the Mediterranean countries occurred gradually and with small transformations that not only affected building techniques (Giglio A. 2006) but concerned a widespread need for the re-evaluation of the classic repertoire of building materials (Mornati S. 2006). Nevertheless, an architecture was born that coexisted with the traditional materials, which was used several times in mixed construction systems, as with adobe masonry (Tavares A et al. 2012-a), keeping the building traditions alive (Tavares A et al. 2013-a). Adobe bricks was one of the most widely used building materials in the world in the past, but the appearance of mixed systems with reinforced concrete widespread in almost all traditional techniques as with stone masonry. An example is the case of housed offices and general service areas in Brindisi (Italy) mentioned by Menghini (2006), with loadbearing structures in masonry using the local tufa stone.

This introduction of the reinforced concrete in the construction, a technique with such potential for dissemination imposes important shared decisions on architects and civil engineers in relation to the traditional methods of construction, new architectural and engineering conceptions and conservation processes. To understand the evolutionary process involved, the transition period must be also characterised, where the new technique was almost considered as a “natural” complement to traditional construction. Its impact on the traditional construction and the ambivalence generated continue to be important issues to take into consideration while selecting the background for the preservation of the mix of new and ancient technique. Nevertheless, the consecutive regulations of reinforced concrete did not mention specifically its application on mixed systems with traditional materials, for this reason the compatibility between both was not a matter with guidelines.

Still, it should be emphasized that the legislation of 1951, the “General Regulation of Urban Building” (RGEU - *Regulamento Geral das Edificações Urbanas*) which replaced the mentioned legislation of 1903 had a huge impact and it is currently applied, despite many temptations to change it. This regulation defines not only guidelines for the spaces configuration, the urban morphology and orientation of the buildings valuing the aspects of sunlight and predominant winds instead of just aligned along the streets, but also define construction guidelines. This last aspect is very relevant, because it does not mention traditional types of earthen construction systems (adobe, rammed earh and *tabique*), but only stone, ceramic brick and reinforced concrete. It also proposes some thickness measures of the walls, beams and other elements, which if followed, will exempt engineered calculations for previous approval. This kind of procedures are one of the reasons that hampers the application of traditional systems, as the values to be adopted in the calculations for the "traditional" construction were not known, particularly in a time with growing engineered solutions of construction. This lack of knowledge progressed as the new technicians were not having any education (practice or theoretical) about traditional construction on their graduation (a problem still presently observed in many universties). However, this national legislation opened the chance for each municipality to present additional and specific guidelines for the application of traditional methods of construction, following the national regulation framework. The Aveiro municipality (an adobe region) started to apply the General Regulation for the Urban Construction of Aveiro (*Regulamento Geral da Construção Urbana do Concelho de Aveiro*) in 1st Jully 1956 which mention rules for adobe specifically concerning foundations, walls and mortars (without specifying the support of application).

3.2.2. Description of the traditional construction system of 20th century

In this research, the traditional construction system (here identified as Solution T) will be considered as the solution prior to the introduction of reinforced concrete and, for this reason, the solution largely applied from the beginning of the 20th century. The solutions of previous centuries can also be identified as traditional, but they are not currently the most common in the building stock. Thus, the following solution will be presented as the main reference to which the others will be compared. It is important to highlight that this traditional system (Figure 3-28) was implemented during a period in which engineered supervision and regulations were already available, and the main traditional characteristics remained for a long time. This is why we propose the term "traditional" instead of "vernacular". This issue represents a topic for debate in future work.

Figure 3-28 – Laboratory tests at Civil Engineering Departament of University of Aveiro [credits Alice Tavares]

The traditional adobe construction system of the central region of Portugal is characterised by a loadbearing wall structure made of adobe masonry with foundations made of the same material in trenches of variable depth. The thicker walls of the foundations were lifted above the ground, forming a marked elevation basis for facade configuration.

An added value of the adobe construction (Figure 3-29) is the strategic existence of a ventilation space between the level of the ground floor and the soil level. Ventilation in this area is guaranteed through small openings at opposite walls, including at the foundations of the interior walls, which allow air circulation throughout the area (Tavares A et al. 2011-a, 2012-a). Normally, the foundation walls rise 0.50-0.60 m above the soil, forming a wall cavity that enables ventilation at both the base of the wall and the wooden floor, thereby facilitating the drying process (Tavares A et al. 2014).

Figure 3-29 – Adobe traditional construction system with timber floors and roof structure [credits Alice Tavares]

This type of solution can also be seen in the Mediterranean regions. This solution is highly relevant to the adobe construction, although other construction systems, such as the stone buildings in the North of Portugal, present similar characteristics. As reported by Fernando Pinho (2000), the height of this ventilation space in the old stone buildings was 0.50-0.80 m. This important aspect was emphasized in Alberti's treatise (Rykwert J. et al. 1996) to promote durability for other construction systems.

Another issue to improve durability is waterproofing of walls. Waterproofing is performed from the foundations to a minimum height of 0.20 m above the soil, but it is quite common to extend it to the upper height of the loadbearing wall.

Interior walls are normally formed by a timber-framed partition or brick masonry. Although the term *tabique* has been adopted in many ancient Portuguese writings to indicate any partition walls independently of the material (e.g., brick, timber), it commonly indicates an earthen technique with a framework of timber recovered by a layer of earth mortar. This technique was so widespread on interior walls that the term is currently used in Portugal for this type of technique only.

The composition structure of spaces and curtain walls/facades is a common housing construction. The interior division by partition walls with a regular and symmetric organisation of a spacing favoured a better distribution of loads, not only because of the decreased span due to an increased number of supports but also because the possibility of connections to transversal partition walls reduces the risk of out-of-plane failure of the facades. Regular sizing construction favoured the structural function. The connections between interior and exterior walls were usually made through metal devices or timber elements that connected the timber posts of the interior wall to the exterior wall anchored in the joints of adobe masonry. The same is observed in some old constructions of rammed earth with stones in gable walls in Lisbon. Although this was not present in all adobe constructions and the corrosion of the metal devices compromises the objective of connection, it was a relevant issue to achieve good stability for the entire structure.

The dimensions of interior spaces were usually approximately 3.0-4.5 m, the restriction of space was not only related to the urban regulations but was also justified by two other aspects: the cheaper regular dimensions of the timber beams in the construction market and the load bearing capacity of the common thickness of the adobe walls.

Therefore, the system is closely associated with a timber structure built to support the floors or the tiled roofing/covering (Tavares A et al, 2011-a; 2012-b).

In later periods, the brick masonry was commonly used for interior walls and for the correspondent foundations.

The coverage area had a protruding eaves facade plan with the use of longer tiles (the *telhão*) supported by a prominent entablement built with cross adobes or ceramic slabs. This guaranteed greater upper protection of the facade due to a greater runoff distance of rainwater, a factor that is the basis of many of the pathologies observed in adobe systems. The application of thinner ceramic pieces replaces the transverse placement of adobe in the projected cornice, consisting of overlapping layers of ceramic plates in a system that respects the cut-out design of the projected cornice. This forms a support base for the ceramic tiles of the eaves, usually *canudo* tile, with the desired projection out of the facade plan.

The recycling of materials was common in several regions, where the existing adobe walls were often repaired by dismantling part of the wall to replace it (mainly corner sections or the replacement of deteriorated adobes) (Tavares A 2009) or was demolished and the same materials were used in new construction or enlargements of the building.

Thus, as in several European countries, the period of the most frequent application of traditional construction techniques was prior to 1950. In the same period, we can observe an incremental decrease in the adoption of adobe construction. However, it is possible to conclude that several aspects contribute to this event and its decreased use in the 1950s. Contrary to what is usually assumed, the introduction of the reinforced concrete was not the principal factor at the beginning of this process. This research concludes that the main factors are as follows:

1. A great increase in the demand for housing due to migration from the interior regions of Portugal to the coastline. This aspect was crucial to the disappearance of the traditional technique. It was observed that in 1950, the number of new adobe constructions did not change in relation to previous periods. Remarkably, in 1952, the housing demand doubled in relation to the previous year. This aspect is a key issue due to the seasonal production of adobe and the manufactured process of production involved in traditional techniques, which made it impossible to respond to the enormous demand.

2. The technicians' education lacked information about this traditional technique with adobe (until the 1950s, most technicians graduated from the Faculty of Engineering of University of Porto – FEUP and Industrial Institute of Porto). Additionally, most of the technicians were not from the Aveiro region; more than 85% were from Porto, a region of stone masonry. The lack of training by universities or schools regarding adobe construction induced a dependency on local designers, the only ones with knowledge about the traditional methods of construction that could adapted to proposals for adobe construction. For a long period of time, the design projects were ensured by civil engineers and not by architects. The main problem emerged with a second generation of technicians (mostly agents of civil engineering and builders) at the end of the 1940s, which revealed a significant lack of practical training in traditional techniques. A number of errors were gradually introduced into the system, decreasing confidence in its reliability. Some examples are (i) the reduction of the section of exterior adobe walls to 0.25 m, which compromised the stability of the structure and reduced the positive factors of the thermal and acoustic behaviour of the construction; (ii) the use of a type of adobe that was previously used only for division walls of the land and that were then applied to dwellings; and (iii) the use of incompatible materials and solutions (the use of cement independently of support) that increased the vulnerability of the system, reflecting the lack of knowledge of the ancient criteria used.

3. Increased confidence in the new technique of reinforced concrete that surpassed the initial problems. This technique was first nationally regulated in Portugal in 1918, although it had been previously used in the country. A more complete regulation was established in 1935, which lead to the widespread of its application. The combination of a faster solution in addition to the progressive role of material marketing for the growing industries of brick and cement completed the means to promptly respond to the housing demand.

4. The Portuguese legislation of 1951 did not include specific guidelines for adobe construction and required certain complementary characteristics and technical proofs of structural calculations that led to a growing mistrust in traditional techniques. The municipal regulations could define guidelines concerning the use of traditional techniques. The problem was that despite its applicability, adobe construction was restricted by the municipal regulation (Aveiro) to just two floors for dwellings in case of adobe foundations (which were the most frequently used). In a time of urban development based on higher buildings, this was another factor that restricted the application of adobe.

5. The changes in urbanism in terms of regulations, urban plans, and the new sizes of the urban parcels were negative factors for the application of adobe due to incompatible guidelines and the value given to higher spans and new architectural movements.

6. Finally, there were side effects of migration (involving wide changes in the social structure). A growing lack of a sense of belonging to the place was a key issue in the decrease of adobe construction use, a problem that continues to exist in the protection of this earthen heritage. The adoption of the traditional construction system is in line with the value of adopting local materials as a means to respect the regional economy and identity.

3.2.3. Timber species used in the construction system (1895-1956)

The identification of the timber species used in the period (1895-1956) was mainly based on the consultation of archive files at Porto, as the Central region has scarce written data available from the period of 1895-1939. This research allowed assessing the importance of the interaction between Porto region and Aveiro region regarding the timber market and industrial processing of timber. Therefore it was considered important the analyses of Porto region to understand what could happen in Aveiro district. For the study of the period after 1940 it was used the archive files of Aveiro district and finally crossed with observations *in situ* (at Centre and North of Portugal).

From the analyses of this research it can be pointed out the existence of a gradual substitution of the species *Pinus Sylvestris* and *Castanea Sativa* (prevalent in previous periods) by *Pinus pinaster Aiton*, which becomes prevalent after 1920's. The other processes of Central region of Portugal and *in situ* surveys show a similar situation.

In the middle of the 19th century the Central region of Portugal exported timber to Spain and England, namely fagus and oak, but also to the North of Portugal (Rodrigues M 2010). However, due to the type of manufactured production of the Portuguese industries, most of them as small scale industries. They were not specialized in just one type of production (Rodrigues M 2010) so not exclusive for timber processing, which some authors reported as a negative aspect for the implementation of a national forestry management. Although the growing interest in this type of industrial exploitation in the Central region of Portugal, the data from the inquiries about national trading of 1890-1930 (*Anuário Commercial de Portugal*, 1895-1930, cited by Rodrigues 1998), shows that the largest number of timber manufacturing industries was at the North (Caetano L J 1986). In Aveiro district it is well known the importance of the coastal lagoon *Ria de Aveiro* as a way used by the industries at the time to transport by boat their materials along more than 40 km (Caetano LJ 1986). This allowed the partial connection of the Aveiro district to Porto which was complemented by the seaport of Aveiro and the seaport of Porto allowing commercial exchanges of industrial materials. This exchange function both directions. Nevertheless, since the conditions of navigability of *Ria de Aveiro* were not appropriate, the development of the railway and road connections brought a higher impulse to the timber industries. Considering the data of Rodrigues about Aveiro region, it was seen that the increasing numbers of timber traders in Aveiro doubled in the period of 1919 to 1930 (Rodrigues M. 2010, pp.322). Nevertheless, it should be considered also that the timber trade did not have as the only purpose the supply of the construction industry. It was very important for the wine industry (of Porto/Vila Nova Gaia), or as an energy source for most industries, particularly before the development of carbon mines for the national market and the implementation of steam or electric engines. Only after, it was possible, a more freely implementation of industries, not confined to timber or hydraulic energy (Caetano LJ 1986). The first steam engine used in Portugal is from 1835, which can give an idea about the high dependency of the Portuguese industries on traditional human labour and also on timber resources, considering for example England where this engine was used since 1785 (Caetano LJ 1986).

This interaction between the North and the Centre was growing along the time and some industries had offices, manufacturing, mills, or warehouses in both regions, mostly near the railway stations or the seaports. The development of roads and railway connections was a key point in this interaction and in the management of timber manufacturing.

In the Centre prevailed the small-scale industries, many of them were family industries (Caetano LJ 1986; Rodrigues M 1998). Sometimes without the capacity to fulfil larger needs. This could represent a problem in periods of significant increase of buildings demand. As reported by Rodrigues (1998) namely for 1905 and 1919-20 in the Aveiro district an increased demand was originated mainly for rehabilitation and enlargements of the number of floors interventions. This justified the use of workers from the North to several construction tasks at the Centre, including also the importation of the timber pieces already manufactured. Furthermore, the number of timber traders in Aveiro (Rodrigues M. 1998) increased again from 1920 and tripled by 1930, strengthening the connection with the Northern market.

In the end of the 19th century, the Portuguese forest was decreasing their common species of *Castanea sativa*, *Pinus pinea L*. and Oak (oak was almost not prescribed for timber structures (1895-1956), but it was used for other parts of the construction (Figure 3-30). They were being replaced by other species more popular to export or with better growth speed for construction and for all types of industries. The increasing demand of timber during the decade 1920's due to the growing need of housing and the emergence of new urban areas can also justify the change of timber species used in the construction. The national importations show a stronger commercial trade with England, Brazil (a Portuguese colony until 1822), USA, France, Germany, Spain, Sweden and Norway (data from Anuário 1917 and 1921). The imports of timber from the North of Europe (*Pinus sylvestris*), USA (*Pinus rigida*) and from Brazil (*Manilkara huberi* - the one identified for this study period) occurred mostly in periods of economic growth, however from 1905 the prescription of these species by the technicians was not high, as can be seen in the study database. Nevertheless, these species were recognized as more resilient for structural purposes, but also more durable and resistant against xylophagus agents decay, despite Castanea Sativa continue to be the most valued. However, the use of those imported species of timber was more adopted for houses and for relevant industries, which is not reflected in this database due to the inclusion of all types of buildings.

The data collected resumed in Figure 3-30 shows that the species applied in the construction during the 19th century had a huge decrease, mostly Castanea Sativa since the beginning of the 20th century and *Pinus Sylvestris* from mostly 1920's. The imported timber species (mainly *Pinus rigida* and Brazilian timbers) were not highly applied for structural elements but they were used for non-structural elements and its application for this objective is low during all the study period. The huge grow of the *Pinus pinaster Aiton* specie usage stared after 1910, and achieved more than 95% of the application for structural elements even during 1950's. This was due to changes in the management of forest and timber market, where the speed of grow of this specie enabled a greater and faster return of investment.

The national data in Statistical National Report of 1921 (DGE, 1925) shows an increase of 22.5% of debarkation of timber in the national seaports between 1920 and 1921, which again allows us to conclude that the national exploitation of timber was not sufficient during the period of increasing building constructions. Moreover, a historical detail should be considered - the influence of emigration (data from *Anuário Estatístico de Portugal* of

1921, 1927 and 1939 - DGE 1925, 1928 and 1941) in the business relationships. Emigration from Porto and Aveiro districts were similar and very significant, in comparison with Lisbon (the capital). It was eight times more for Brazil in 1921, 1927 and twelve times more in 1939. The emigration from Porto and Aveiro districts in 1939 (DGE, 1941) represented 47% of the national emigration to Brazil. Also the emigration from Aveiro district to USA in 1921 and 1939 (DGE, 1925 and 1941) was almost three times more than the values of Porto or Lisbon. Therefore, the commercial trades and social changes involving Brazil and USA were established, facilitating also the timber market. This could also have an impact on the choice of timber trade axes, not to mention the commuting return of the Portuguese people.

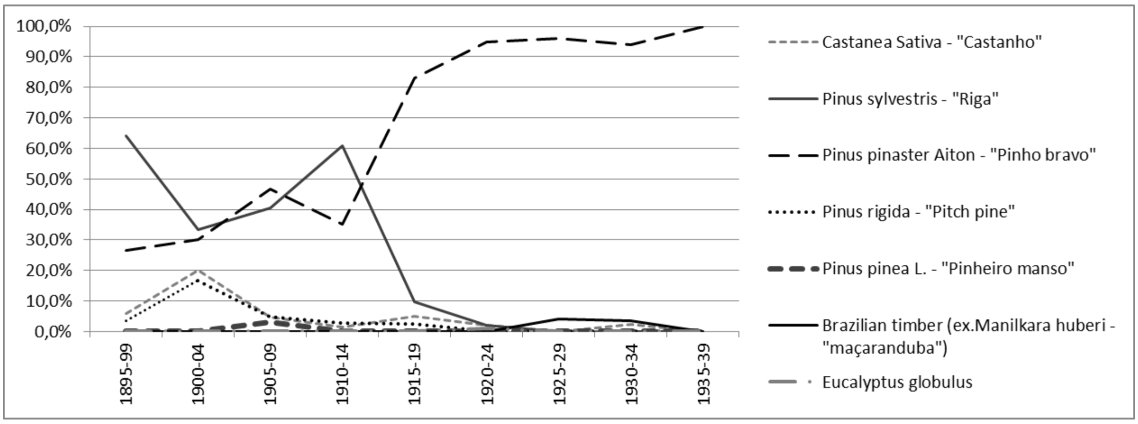

Figure 3-30 - The use of specific timber species in Porto structures of the roof [credits Alice Tavares]

Nevertheless, from the data of (Figure 3-30), can be seen just a small reflex of this in the prescription of timber species for structural purposes by the technicians, reflecting a tendency, where architects choice were more to high quality timbers (imported or *Castanea Sativa* or *Pinus sylvestris*). Unexpectedly the same was observed for their application in structural elements in industries. In relation to the eucalyptus specie (probably *Eucalyptus globulus* as it is the most disseminated in Portugal), the prescriptions in this period are quite irrelevant in the North and Central regions. However, it was found in *in situ* assessments in the Central region (Aveiro district) examples of roof structures with pieces with round section of this timber, but mostly of interventions after de 1950's. As Rodrigues pointed out the Eucalyptus was known in Portugal since 1774, examples through the Baron Von Müller and by Baron of Massarelos in Vila Nova de Gaia, at Formiga Farm, in 1852 (Rodrigues M., 2010). The provenance of the eucalyptus was mainly from Australia. However, its plantation for industry purposes occurred in the middle of the 19th century (Rodrigues M. 2010). The data of the Annual Statistical report of 1939 (DGE, 1941) shows that despite the growing interest on this species, the new plantations by the government represented just 0.03% of the total species planted in national forests in that year and restricted to coastal areas. Oak and pine were prevalent for plantations at the time. Crossing this information with the citations of Rodrigues (1998) about reports promoting the new species (eucalyptus), it can be concluded that in this period, the growth of the implantation of this species was mainly through private entrepreneurs. In Aveiro district, despite some controversy, this timber species replaced progressively the plantation of *Pinus pinaster Aiton*, mostly because of its faster growth and the later interest of the paper pulp industry. In 1920, the eucalyptus forest represented 2.9 % of the total forest of the region (Rodrigues M. 2010). However, its application for construction was not significant as confirmed in *in situ* assessments.

Finally, in the region of adobe construction the use of timber as structural element and specifically for the roof structure, was found in more than 90% of the constructions in 1950, which shows the high relevance given to the compatibility with this traditional type of construction.

The identification of the timber species in the assessment of this type of structures is important. Mainly because each species has differences in terms of durability, crushing strength, bending and stiffness, decay class resistance, and other aspects that are usually addressed in the assessment of a structure, previous to any conservation action. As pointed out by ICOMOS, this information is essential to fully understand the structural characteristics in its original and earlier states, on the techniques that were used in the construction, on the identification of later alterations and their effects, on the pathologies, and finally, on its present state (ICOMOS, 2003). Some of the inaccurate decisions resulted from the contradiction of adopting current standards based on wood of lower quality that was typically used in heritage buildings. The result of misevaluating a species grade frequently resumes on an overly conservative estimate of the design values followed by unnecessary replacement, repair, and retrofit decisions along with associated unnecessary project costs and the loss of historic fabric (Anthony et al. 2009 pp3). This is an issue of major importance regarding ancient timber structures.

3.2.4. Introduction of reinforced concrete ring beams and platbands

Solution RgB is a system similar to the traditionally used (Figure 3-31), which main variations are as follows: (i) replacement of the interior timber-framed partition walls by fired brickwork (mostly with hollow bricks), (ii) reduction of the exterior walls thickness using adobe, (iii) the existence of platbands on the main facade/curtain wall, with gutter drainage into the perimeter, as observed in changes on the main facades during 1920s, with the introduction of those elements, that may only partially occupy the facade/curtain wall (Figure 3-32), as usually, platbands were not present at lateral or rear facades, (iv) use of reinforced concrete ring beams (RgB type, Figure 3-33). This ring beams have the width of the wall and at a height usually not exceeding 0.10 m (which is in accordance with the regulation of 1918 for the reinforced concrete, that imposed a minimum of 0.08 m). They were set at the transition area of the foundation walls/exterior loadbearing walls and immediately below the timber support structure of the ground floor or of the covering. Also they could be set at the lintel height or for the construction of prominent elements in the curtain wall/facade (Tavares A et al. 2011-a; 2012-a). This also answered to the imposition of higher dimension (1/10 of the area of the room) of the openings by the Decree-Law of 1903. This aspect in some situations of the configuration of the wall could be an obligation with a negative impact on the adobe construction which was "solved" through this ring beams at the level of the lintels. This aspect that reveals the concern in looking for a better mechanical function of walls through the introduction of the so-called "reinforced ring beam", which was achieved with the application of 2-3 round smooth steel bars embedded in "cement mortar" (Tavares A et al. 2012-a). This solution is commonly present in buildings after 1910's in the Aveiro region, increasing the number of steel bars (4 bars of 5/16" along the wall) and regularly spaced (0.20 m) stirrups of ¼", a solution adopted during the 1940's, as can be seen in VA factory neighbourhood. This ring beams are normally continuous and can play a double role, namely distributing into the walls the vertical loads from roofs and pavements, and restraining the walls to out-of-plane movements if properly connected. This reinforcing measure can help in preventing out-of-plane deformations, and consequently roofs collapse or building corner failures, typically observed in traditional constructions (Tavares A et al. 2012-b). Nevertheless, a less durability of the materials used in these ring beams are sometimes the main reason of decay of adobe buildings with ring beam solution.

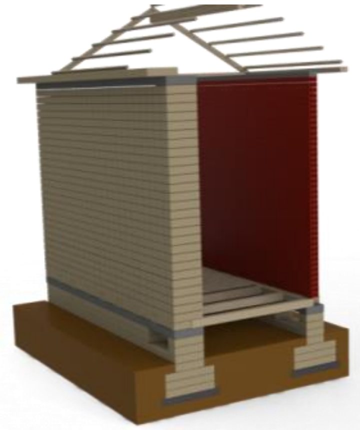

Figure 3-31 - Solution RgB [credits Alice Tavares]

Figure 3-32 – Design plan to change the front façade introducing RC beams [credits Municipality of Ílhavo]

Figure 3-33 – Photo of an example of RgB solution [credits Alice Tavares]

This solution was the first that adopted reinforced concrete and aimed to overcome some of the problems detected in the adobe buildings associated with higher stress areas as the lintels of the openings. The aim was to thereby avoid the diagonal cracking from the angles of the openings, that usually introduced water into the lintel. Moreover, these reinforced concrete beams could be applied also to strengthen the support zone of timber structure of the floors and roofing, simultaneously increasing the rigidity of the support area, representing a similar purpose observed in the traditional construction through the use of a row of bricks. Additionally, this reinforced concrete beam confine the walls and tie them. This detail is particularly important in the corners, since the adobe masonry has sometimes problems in this area due to poor imbrication of adobe blocks or due to the thickness decrease of the walls observed in more recent solutions. This was most relevant for constructions after 1930's and in consequence it was more difficult to avoid the vertical crack in the area of the corners.

Concerning the use of the reinforced concrete ring beam solution two important issues must be highlighted. In an initial stage of implementation / testing, the bars introdution along the walls, were joined or not by stirrups where the cement may not be used. Moreover, the applied mortar was different from the composition used in the rest of the joints. This was observed in old buildings *in situ* surveys, the colour and texture of this mortar is different, but it does not have the resistance expected for a cement mortar. For this reason, to achieve more details about the composition of this ring beam were made some laboratory tests of the sample removed from the ancient theater of the city centre of Ílhavo. This tests revealed very low levels of cement in the composition. Curiously, this type of ring beam was at the time named "cement ring beam" although its composition could have only vestigious amounts of cement in an initial stage. In this specific case (city centre theater mortar) it was also observed that the mortar around the steel bars had lower resistance and was falling apart at touch, probably due to decay caused by the effects of polution and salt presence. So, at the present its function is simply to cover the steel bars, which already show a high level of corrosion. This situation compromises the structural functionallity of the ring beam of this building probable of 1920's, but mostly shows some concerns to the effectiveness of the function of this solutions.

In later periods, in the beginning of the 1940's the composition of the mortar used in these elements were: cement/ sand/ gravel with 1:3:5 ratio when applied in lintels and 1:4:6 ratio when applied in ring beams or short thin slabs.

The reinforced concrete ring beams of exterior walls were connected with the same type of beams of the interior walls at the same level, despite the difference of materials between the walls (adobe/brick). The only difference was the beams thickness. This solution was applied in the dwellings of the working-class neighbourhood of the Vista Alegre factory, but also in many other buildings of the region. The use of those leveled beams could also be seen at the level of the lintels instead of the timber structure of the roofs. In this case, if there is an application of a system of shutters the beams did not complete the entire thickness of the wall or they could be slightly detached from the exterior wall. In other cases was applied short lintels and at a different level the ring beams.

In another situation, a later application shows the importance that was given to the use of reinforced concrete elements to solve the problem of tensions in the corners of the construction. This results in sections of reinforced concrete beams extending approximately 1.20 m, for both sides without the continuity of the original solution which embraced the whole construction. The objective was simply tie the two walls, although sometimes the section of this short beam was not sufficient to restrain the movements of the walls. Thus, these beams sections had the same height of an adobe, inserting a row and they were usually applied over 2/3 of the total height of the wall, not necessarily as a basis to support floor joists or roof.

In archive files of 1956 it is mentioned that the concrete braces are placed on asphalt when applied at the level of thresholds and based on a mass of hydraulic lime with sand in the rest of the situations. This shows an advance in the recognition that the concrete itself did not solve the problem of waterproofing, an idea disseminated in the beginning of its application on the level of the upper part of the foundations.

In terms of the rest of the construction concerns were maintained regarding the base of the foundation, but it was observed that the architects that supervised the application of the urban plans recommended that in adobe constructions a layer should be applied in all the area of the construction, before the foundations built.

Again it is maintained the use of solid or hollow bricks for: sections of wall underneath window sills continued to be adopted, and oftenly to form the arches of lintels of exterior and interior doors and windows.

Concerns with waterproof barrier remains and the use of hydraulic lime on mortars and adobe blocks was growing.

This solution has a widespread application and is used by all kinds of technicians, with prevalence for civil engineers and technical staff of civil engineering.

3.2.5. The use of punctual piers, beams and some slabs of reinforced concrete

This type of construction system is an alternative used in Show buildings (theatres, cinema) and dwellings, and was also adopted by some architects. As an example, the architect Samuel Quininha’s proposals are a mixed construction system (adobe, reinforced concrete and brick). He even built for himself a summer house at this location using reinforced concrete pillars to support 8.0 m span fitted to exterior adobe walls. In the late 1940’s he once again presented projects using adobe for dwellings. Again, reduced dimensions in regular metric spaces were kept, which is compatible with the adobe construction system and does not require the use of reinforced concrete piers in the construction (Tavares A et al. 2012-a). That is why this type of solution did not completely substitute the traditional system.

The main characteristic of this type is the use of adobe in exterior resilient walls over which a few reinforced concrete slabs (RgB/S and RgB/S/P types) are supported mainly for bathrooms, balconies and terraces at the upper floors (Figure 3-34 to Figure 3-36). It can still maintain the ventilation of sub-floor cavity, given the presence of simultaneous application of suspended timber floors in the remaining spaces. At ground floor level, the use of a concrete groundbearing floors slab is common in service areas (kitchen and bathroom) and at the entrance hall, normally surfaced with hydraulic brick. The 1903 legislation obliged the use of fire-resistant materials for the floors of the kitchens (which was adopted in the regulation of Porto). Later on the specific legislation about fire prevention will impose the use of reinforced concrete slabs in these areas. This concrete groundbearing floor was built in three stages, corresponding to three layers: a first one, with a height of 0.05 m of ceramic shards completely dry and well compacted; a second, a well leveled layer of a mixture of cement and sand with 1:5 ratio added to ceramic shards, again with a height of 0.05 m; a thirdly, a floor screed of cement and fine sand with a ratio of 1:4 with 0.02 m height. Nevertheless, this is a configuration from 1943 (VA factory neighbourhood), but other configurations were also applied.

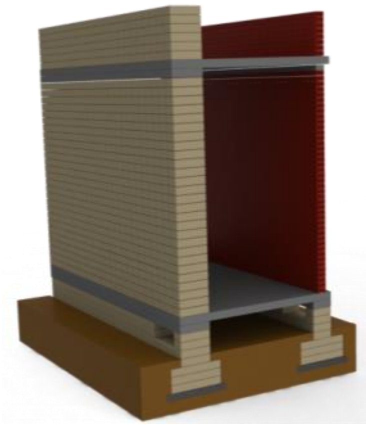

Figure 3-34 - Solutions RgB/S and RgB/S/P [credits Alice Tavares]

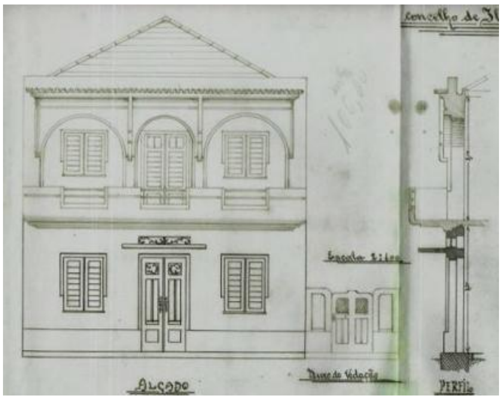

Figure 3-35 – Design plan of RgB/S [credits Municipality of Ílhavo]

Figure 3-36 – Photo of building (RgB/S solution) [credits Alice Tavares]

In this solution that it was also applied reinforced concrete ring beams with characteristics from solution B (RgB type) and again concerns were found with the anchorage and bracing of walls and the reinforcement of corners. However these reinforced ring beams were higher than 0.10 m (0.20 x 0.30 m^2, as an example) and acted as support beams connected to slabs. They were commonly embayed on the walls, through all thickness of the wall, and applied also for interior spaces, to increase the spaces and break with the dimensional restrictions of the traditional type. These beams had a mixture of cement/

gravel/ sand with a ratio of 1:3:5 or cement/grit/crushed shard with a ratio of 1:3:6. The same composition was applied for reinforced concrete slabs. Progressively it was increased the thickness of reinforced concrete beams and slabs.

The slabs could be rigid reinforced concrete commonly used during 1930-40's, as very thin, with 0.10-0.12 m thickness or lightened slabs with hollow brick (0.33x0.22x0.12 m^3) with 0.03 m of compression zone of floor screed. This had the purpose of using larger spans with less load applied to the walls, adding to a decrease in construction costs. On the other hand composite slabs with iron beams complemented with ceramic slabs or bricks were also used. This slabs were for service areas (kitchens and bathrooms), the groundfloor level or at the level of the 1st floor, as balconies, terraces or flaps on the front or back facades (Tavares A et al. 2011-a).

In the 1940's this slabs presented some variations with irons ¼" to 0.22 m mesh or rods 5/16" crossed to the mesh of 0.18 m. The mortars used consisted of cement, sand and gravel on an 1: 3: 5 ratio (Tavares A et al. 2011-a) or on an 1:5:8 ratio. Although these concrete slabs were used in service areas of the dwellings they were also used as an imposition of the fire regulation comprised on municipal regulations (example of Porto regulation) to restrict the spread of fire. In this case they were used commonly in warehouses, barns, sawmills, factories, but also in housing to separate the comercial groundfloor from the upper housing floors. In this cases they usually have 0.16 m thickness. The use of tables of Vasco Costa (CMI-a 1942-1960) to help on the calculations of the reinforced concrete was common (Tavares A et al. 2012-a).

The first concrete piers, in single or small numbers, appear to support larger spans in specific interior areas, although solid brick priers are still the most adopted solution. The use of RgB/S/P type was commonly, despite the increased number of concrete pillars (not necessarily aligned) in the buildings. There are some situations where the support of arches, either interior or exterior, is made of brick piers built into/fitted in walls. Interior walls are normally made of brick. In project plan sections it is maintained the wall thickness reduction as the construction level increases.

At this stage the first pillars arise sporadically, only as a means to overcome the need for greater structural versatility of certain functional areas, like the living room, that even becomes the focus of changes in existing buildings, in the 1950's. The growing importance given to this space, as a place of social interaction, makes it one of the first areas to suffer changes in the new Modernist buildings. Settling a richer articulation with other areas of the house. In some cases, the interior stair was used as sculptural element to enrich the architecture and possibly also it was of reinforced concrete.

The aim was to meet the needs of comfort, but also an approach to the Modern Movement of Architecture, through the introduction of: terraces; balconies with greater extension outside the limits of the walls; flaps in the entrance area. However, the search for new spatial relationships in the housing causes the decrease of use of regularity and symmetry of the traditional system and start to use greatest range of spans and structural variation which demand new architectural changes.

3.2.6. Adobe hybrid solution with reinforced concrete

Solution PORT/S (Figure 3-37), the most hybrid solution with adobe (which was not always as structural element) and reinforced concrete (as the structural element) reflects the longevity associated with the use of adobe, but also the first step of the decrease of the knowledge about the technique. It is most frequently observed in a later period (in the 1950s and at the beginning of the 1960s), less used in new construction and more seen in expansion projects. The construction of adobe walls was adopted to expand existing spaces at the ground floor level, over which a reinforced brick slab or other concrete solution was supported and onto the brick walls for the upper floor were built. This solution may also have had the purpose of reducing loads onto adobe walls, thus acting merely as a support to the timber structure of the covering.

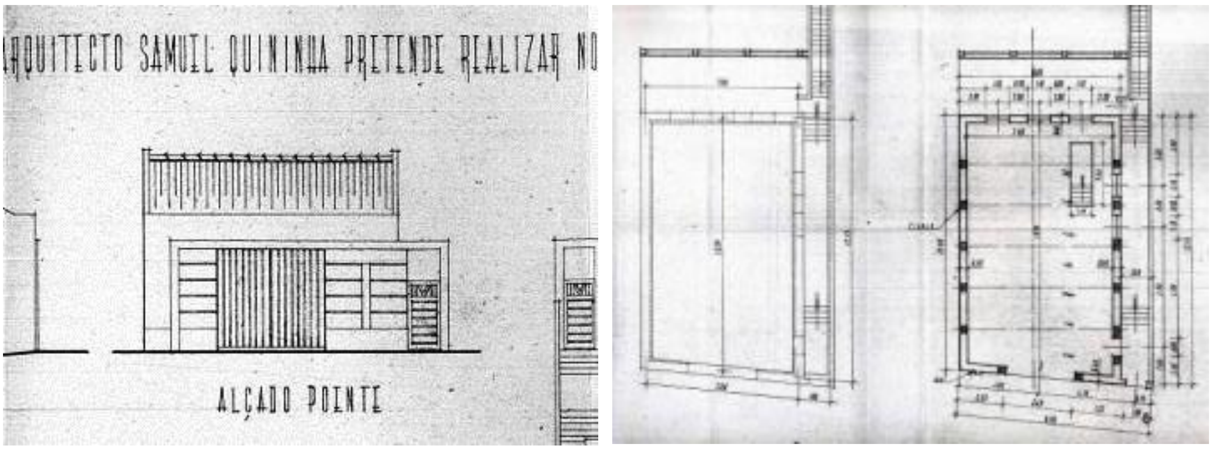

Figure 3-37 - Building design of the architect Samuel Quininha – Garage - future extension for housing, 1946 [credits Alice Tavares]

At the ground floor level it was common to use the concrete groundbearing floors slabs for all the spaces and progressively to abandon the under floor ventilation area of the walls (Tavares A et al. 2012-a). In many cases it was adopted the reinforced concrete solution, PORT/S type, due to a less and progressive confidence and lack of knowledge about the traditional technique, by the new building designers. Yet there are cases of new construction, fewer, in which the first floor is of adobe masonry and the second of brick masonry, but where the structural function is usually reserved to the reinforced concrete structure instead of the traditional loadbearing. Nevertheless, in the most cases the reinforced concrete structure did not completely guarantee the whole resistance function, mostly until the 1950's, due to a late preference for loadbearing masonry, regardless whether they were of adobe or brick.

The progressive use of a complete structure of reinforced concrete with just the adobe to fulfill the structure of the walls was mostly used to achieve the larger spans of spaces and overtures on the facades imposed by some solutions of the Modernism (Tavares A et al. 2011-a).

In this kind of solution the ceiling may have a horizontal slab "reinforced concrete" which supports the timber roof structure in place of the traditional system. As an example, the design plan of a dwelling of 1956 the slab is described as a reinforced concrete with 0.03 m of compression layer above the part with hollow brick (0.12 x 0.22 x 0.30 m^3). The compression layer was well compacted and made with a mortar of cement/sand with 1:3 ratio, to which was also included 5% of diatomaceous earth with the expectation of 'improving the waterproofing'. This slab was not connected to the walls but resting on them under a dry paper cement bag previously tarred, to allow a free expansion of the slab. Finally, it was covered with copper sheet in all the necessary areas to avoid infiltration.

3.3. Foundations of adobe buildings

The proposed study on the adobe buildings in central region of Portugal based on data collected *in situ* and archive files led to interesting conclusions useful for the development of solutions regarding to foundations.

Foundations are a hidden component of building with great importance for the proper functioning of the overall stability of a structure. For this reason, in addition to questions concerning: the type of foundation soil, materials, size and depth, type of connections, the base for the footings and transition area with the wall, also durability factors are equally important and referred to in ancient writings (Rykwert J et al, 1996). Concerns about the the soil conditions are present in the Portuguese legislation (1903 and 1951) involving the public health topic and the salubrious state of buildings, including the silt soils areas, the most common at adobe construction region.

The study focused on the foundations (Table 3) shows the following issues as fundamental for characterization of old adobe buildings:

a) Preparation of the base of soil of the foundation. Several times the base of the foundation was prepared through a more rigid layer of mortar with addition with bricks or stones. Later on for this purpose was adopted the cement floor screed. Although in many cases the foundations lay directly on the ground, in other cases the concerns about stability improvement and diminishing the rising damp oriented to the other choices.

The foundations with wooden pilings (*estacaria de madeira*) were current in areas close to the coastal lagoon (*Ria de Aveiro*), given the alluvial/silt soil characteristics. It can be considered that the piles foundation (*fundação por estacaria*) can be regarded as a consolidation technique of foundation soil or to guarantee the correct load transmission of to unstable silt soils or sensitive to changings in the surroundings. In later constructions (during the 1940’s) continues to use this method.

Another solution used reinforced concrete pillars on footings with about 0.40 m per 0.65 m wide by 0.25 m height, this was supported by a wooden planking (*tabuado de madeira*) with 0.65 m x 0.2 m x 0.03 m^3 (thickness), with more beams with 0.06 m x 0.10 m^2 with 0.10 m height squarely spaced that were connected to pine cuttings (*estacas de pinho*) with 3.00 m x 0.15 m^2 with a spacing of 0.50 m between them. Even in 1956, it was referred that due to the bad conditions of the soil foundation a timber pile structure was proposed above which it was built a layer of adobe masonry with hydraulic lime until a depth of 1.20 m. At the ground level above this base for foundation it was applied a reinforced concrete beam to transmit the charges of the upper construction walls to this structure.

Nevertheless, the Regulation of Construction of Aveiro (1956) already had two impositions of construction control for the piles foundation for silt soils near the coastal lagoon: firstly, impose several days waiting after the settlement of the piles to continue the building and secondly, the supervision/approval of their stability by the technicians of the municipality before the continuity of the rest of the work.

On the other hand, some different solutions were adopted to prepare the base of foundation with the different purposes as the protection against animals (rats) and insects (termites mostly) from the soil. For this type of foundations protection it was reported, during the 1930's and 1940's, the use of a cement based made of less resistance concrete/light concrete (*betão magro*) with stoneware basis shards and bricks added to cement mortar and sand in a 1:5 ratio. The use of recycled materials for this base was present in some of the architectural design plans of VA during 1939, referring similar materials composition. Later on, during the implementation of the General Plan of the city centre of Ílhavo (CMI a/b, 1945-1948) the architect/urbanist Carlos O. Ramos (the author and supervisor of the Plan) would recommend the use of a cement based (which could be reinforced), not only along the area of the base foundation walls but throughout the implantation of all area of the building, referring to a similar goal. Above this cement base were placed the adobe walls of foundation (Tavares A et al. 2010-b). In some cases this cement base is identified as having 0.08 m thick.

b) Depth, thickness and materials. In the earthen construction, the foundations of ancient buildings presented some variations including the use of thin bricks or stone. However their use was limited to the 20th century, in opposition to adobe commonly used even after 1920's. Above this base the foundations was built with 0.80 m thickness, which sometimes included a first layer of the foundation with the known limestone of the region (stone of Eirol) with a height of 0.50 m, above which adobe masonry was applied.

The use of stone was a slight improvement in resistance to capillary rise in saturated soils and to water effects, such as rainwater drainage and rain impact in the base of the building, particularly because in many cases there were not gutters fixed beneath the edge of a roof to guarantee the outflow of rainwater. This led to a high level of humidity in the perimeter area of the building. This situation changed in Portugal after the application of civil legislation through urban regulations involving private property and the protection of public health, which required the control of rainwater drainage at the level of the edge around the perimeter of the building, forbidding in some cases the edges in the front facade and requiring the construction of the platband. This aspect had an impact on the conservation of the base of the buildings (embasement and foundations) and promoted the need for a public drainage system, which was not generalized at the time. The foundations of adobe constructions were continuous (still recommended in the 1951 Regulation) for both exterior and interior walls that connected. During the 1940s, the foundations of the interior walls (of hollow bricks) were made of solid bricks a height of 0.80 m above a reinforced concrete slab with an approximate thickness of 0.30 m. The interior walls usually had thinner foundation walls and less depth due to the lighter material above, such as *tabique* walls or thinner adobe or brick walls, which usually had less charge to transmit to the ground. In terms of the foundation materials, older buildings (prior to the 19thcentury) have a foundation of stone masonry, some bricks and earth mortar. However, considering the scarcity of stone in the region, its origin could have other sources: stones from merchant ships that were used as ballast and were removed from the ships to receive merchandise and re-used in construction, the reuse of stone from the demolition of churches, the Wall of Aveiro city and other small palaces, or stones from the rivers. The recycling of building materials was apparently a common practice, as demonstrated by the diversity of materials that can be found in old buildings, such as sugar amphorae, tiles, and stones.

The use of Eirol sandstone or granite continues with few references until the end of the 1940's and was prescribed mainly by technicians from the innermost regions, such as Águeda. This was probably due to the greater proximity to the stone areas within the district. The brick foundations were mainly used to support the walls of the same material. In 1935, the application of a layer of cement with hydraulic lime (volumetric percentage/ratio – 8:4:2 or 10:6:2) for the foundations extended 0.10 m from each side of the wall. In the late 1940s, composite foundations were used from an old solution of concrete with a cement trace of 300 kg, 400 l of sand and 800 l of gravel (the cement was usually indicated in weight units and the rest in volume units), which was recommended in the concrete regulations of 1918 (Decree 4036). During the 1950s reports included less resistant concrete with a ratio of 1: 6 (cement: gravel) or the use of cyclopic concrete. The lack of stone continued during the 1940's. Concrete was not used in the usual manner for foundations; instead, adobe was used with hydraulic lime in its composition. The use of adobes with hydraulic lime became common practice during the 1950s and was still reported during the 1960s, complemented by laying mortar of hydraulic lime and sand in the ratio of 2: 5. This is due to the application of the Regulation of 1951 (RGEU). In addition, the use of wall foundations up to 0.50 m above the level of the outside ground was recommended, as was the use of hydraulic masonry, which was durable and waterproof and was made of stiff and non-porous materials. Independently of the 0.50 m height of application, it was observed that the use of hydraulic lime would be applied to the entire exterior walls during the same period.

The application of the adobe on foundations was predominant in the 20th century, representing 97% of cases in the area of the case study of Ílhavo in 1956. Amazingly, it was the last component of the traditional adobe building system to be used in construction, although this change occurred earlier in Aveiro than in Ílhavo (Figure 3-38, Figure 3-39).

Figure 3-38 – Theatre of Ilhavo [credits Alice Tavares]

Figure 3-39 – Photo of building with adobe foundations [credits Google Earth]

Despite the uncertainty about this circumstance, the fact is that even when starting the application of reinforced concrete in structural elements in the construction system with brick masonry, technical designers continue to mention the prescription of adobe for the foundations in their writings added to design plans. This foundation was interrupted by the foundations of concrete pillars, renouncing the logic of full continuity of the wall foundation that had previously been applied.

Another notable aspect is the gradual decrease in the depth of foundations and their thickness between 1920 and 1956. This may be due to decreased thickness of the walls and floor heights (mainly since 1945), mostly after the implementation of the Urbanisation Plans and Regulations. After that implementation, the region maintained the demand for dwellings of small height (usually no more than two floors) as single-family or bi-family instead of multifamily buildings. In Aveiro, the “General Regulation for Urban Construction of Aveiro - RGCUA” in 1956 mentioned that the use of adobe on foundations was restricted to buildings with only two floors. In some cases, this fact may also be associated with characteristics of the soil foundation of the new expansion urban areas, whereas in other situations, it may be associated with the decrease in experience and knowledge of construction quality among other players who were recently present in the construction market.

c) Corners of foundation. In some cases, the corners of the foundation perimeter were reinforced by replacing the adobe blocks by ceramic slabs or stone blocks in those areas in mixed layers. This reinforcement could represent up to the full height of the basement (usually 0.30 m to 1.00 m above ground level) or could even continue along the wall, interspersed with the adobe rows. For reinforcement, the same strategy was also observed in stone masonry involving great care in the placement of stonework (*cantaria*) in the areas of the corners.

d) Ventilation of the base of foundations and level of exterior ground floor.

Based on the construction in older buildings (prior to the mid-nineteenth century) and based on data collected *in situ*, ventilation space may not have existed. In contrast, the ventilation space was the entire ground floor, which could not have housing functions and was used for agricultural storage, wine cellars or as a sanitary space, usually with a very low height (less than 2.0 m). Again, the question remains of the absence in smaller buildings. It seems that its introduction as simple ventilation space for the base of the building could have occurred during the 19^{th} century, possibly due to the widespread introduction of living spaces on the ground floor, the predominance of one-floor buildings or the association of housing areas for domestic employees, the use of adobe as exclusive material on the foundation walls, and/or the use of a timber structure for the ground floor. We also conclude that in the early 20^{th} century, the ventilation of the sub-floor cavity had a greater height than in the 1940s and was above the 0.60 m recommended in the 1903 Regulation, with greater sizing of vents on the facade as inside at the level of the foundation/basement of the construction. There was still a concern about the placement of vents on opposite walls to ensure effective ventilation, an aspect mentioned in the writings of the design plans. In several other cases, the use of concrete floor screed (*massame de betão*) at the ground floor to the service areas of the kitchen and toilet facilities (Tavares A et al. 2011-a) stopped the ventilation process strategy, as in the rest of the sectors of the building blocks. However, regional regulations imposed a difference of 0.20 m between the levels of the interior ground floor and the exterior level of the street. Given the steady decrease in height of ventilation areas prior to the 1940s and their near extinction in the 1950s, maintaining adobe walls represented a drawback to the durability of adobe buildings.

e) Upper part of the foundation and base of walls.

Where there was greater constructive care, a layer was applied that was made of ceramic thin slabs or even wood logs, which allowed closer control of the levelling of the beam. Because it was the first part to suffer deterioration due to eventual rising damp, it offered a piece that could be sacrificed and subsequently replaced. In 1942 at a VA factory in the working-class neighbourhood, brick was layered in two rows for the support of the timber beams. In this case, it was to increase the rigidity of the support area and diminish the direct contact with the wall adobe blocks, which were more likely to absorb moisture. The same strategy was followed at the upper level of the roof structure. Additionally, thin bricks or thin ceramic slabs were applied under timber structural elements as a transition element between materials (adobe/timber). This could help to distribute the load and prevent local crushing in the support area of the adobe walls. In the transition area between the foundation and the upper wall was applied a waterproof barrier of asphalt, tar or similar material below the timber structure of the floor level or below the concrete beam. Other solutions were identified at in situ surveys of centenary buildings, which show a particular mortar in this transition area. This mortar presents a colour and consistency different from that used in the rest of the construction. During the 1940s, diatomaceous earth was used in waterproof barriers; this particular case will be addressed in chapter 5. Nevertheless, both situations are discussed in this study with preliminary conclusions about their efficiency.

During the 1940s, civil engineers prescribed the use of diatomaceous earth added mostly to cement mortars with the same purpose of waterproofing. The recommendation of a waterproof barrier for this transition area is also present in the 1951 Regulations, although it was not mentioned what materials should be used. Nevertheless, it also required the exterior protection of the walls with this barrier up to a wall height of 0.50 m higher than that recommended in the 1903 Regulation (0.15 m above ground level). At this level, the application included the entire thickness of the wall and the wall basement. The imposition of the use of non-porous and rigid materials for foundations counteracts the use of adobe. It seems that this approach was not totally followed because even at the end of the 1950s, adobe was widely used in the foundations.

Table 3.1 summarizes the foundation characteristics of the adobe buildings, indicating the prevailing values of each period. The type of mortars used will be presented below in a specific summary table.

FOUNDATIONS CHARACTERISTICS

	19th CENTURY	**20th CENTURY**				
		1900-1919	**1920-1939**	**1940-1949**	**1950-1960**	**1903-1956 REGULATIONS**
MATERIAL USED ON THE MASONRY	Earth/Sandstone Brick Adobe Timber piles	Earth/Sandstone Adobe Brick Timber piles	Adobe Brick Timber piles Concrete	Adobe (129/140) Brick (1/140) Concrete (9/140) Stone (1/140)	Concrete (4/198) Adobe (193/198) Brick (1/198) Stone	Waterproof material
WIDTH	> 1.20 m*	> 1.0 m*	> 1.0 m*	1.0 m – 0.50 m	0.8 m – 0.50 m Mostly – 0.60 – 0.8 m	
DEPTH	Variable	Variable	Variable	Variable 1.20m -0.50 m Mostly – 0.7 – 1.0 m	Variable 0.80 m – 0.50 m Mostly – 0.7	0.50 m
VENTILATION SPACE AT THE BASEMENT	It didn't exist in the most of the cases or it was the whole ground floor. *	Grounfloor with low height, usually less than 2.0 m. * Height of 1.0 m – 1.5 m.	Height of 1.0 m - 0.50 m. * Some cases without it.	Height of 0.50 m - 0.30 m. Several cases without it.	The most of the cases without it.	0.60 m (1903) 0.50 m (1951-1956)

* Data from in situ surveys - Aveiro region; Legend: material (number of identified material solution/ total number of validated files of material solution)

Table 3.1 – Synthesis of foundations characteristics [credits Alice Tavares]

3.4. Walls (exterior and interior), mortars and renderings

The use of adobe masonry was prevalent during the middle 19th and 20th centuries until 1950, when it still represented 87% of the proposed solutions built in the case study region. The decreased use was significant after this year; in 1956, adobe masonry only represented 39% of the cases in the studied area. This is a region with good natural conditions for adobe production due to the quality of the natural materials, which also favour the growth of industrial ceramic. Improvements in the production and in the transport systems of construction materials with regard to the seaport conditions had a significant impact on the type of building and materials used. However, it should be emphasized that the number of constructions built with adobe did not decrease significantly in this period (1950-1956) but was the result of an increasing housing demand. This led to an increase in building construction with brick masonry because the adobe production was seasonal and was not prepared for such unexpected production demand. This is the why the percentage of adobe construction seems to rapidly decrease, which, in fact, was not the case; the number of adobe constructions remained steady in the following years. However, a gradual decrease was observed after 1955 due to the aspects already discussed.

The sizes of adobe blocks vary from region to region and can even vary in the same construction depending on the area of application (ground floor, upper floors or platbands, interior or exterior). In addition, the composition of adobe blocks can present differences depending on the place of production. Although in many cases the location of production was the same as that of the construction of the building, the trade of adobe was also a common event. For this reason, many buildings present adobe blocks that have the marks of their producer.

In situ surveys allowed the recording of a wide number of sizes of adobe blocks, which are presented in Table 3.2. We can observe that the sizes did not only vary depending on the producer or even on the region but also varied based on time. Further research is needed to assess the reasons for some of these aspects.

Adobe sizes blocks (cm) in principal regions of in situ surveys

Aveiro and surroundings	Ilhavo and surroundings	Vagos and surroundings	Anadia / surroundings
48x10x…	50x10-11x20	48x11,5x20	48x14x22
43x11x29	45x30x10	47,5x11x28-30	47x11x21
42x10x…	43x10x26	46x10x24,5	46x14x22
42x10x…	43x10x20	42x12x22	46x10x25
40x11x23	43x8,5x22	42x10x32	44x11x31
38x11x29	42x11x27		44x10x22
30x10x…	41x8,5-10x19		43,5x10,5x23,5
	40x12x20		43 x 12 x 23
	40x11,5x34		42 x 11 x 23
	37,5x10x30		42x12x18-20,5
	38x10x34		
	31x10x…		
	30x7,5x20		

Table 3.2 – Adobe's size (from in situ surveys) [credits Alice Tavares]

The walls' thickness decreased from the 19th century until the 1950s (Tavares A et al. 2011-a) in a process that cannot simply be justified by the decrease of the floor height but also as a consequence of legislation, municipal regulations and changes in the process of construction.

Given the nature of adobe, the placement of openings in the facade had to be supported by wooden pieces embayed in the masonry and placed in this assembly to serve simultaneously as mitre fasteners (*elementos de fixação do aro*) and alignment guides. This followed a regular metric that was also used for baseboard (*rodapés*) placement, the fixation of timber stairs and other timber construction components. Because adobe does not allow direct nailing, wooden wedges (*calços de madeira*) were placed in the adobe masonry Figure 3-40 during the construction process (Tavares A et al. 2011-a), which required high technical abilities to guarantee good control.

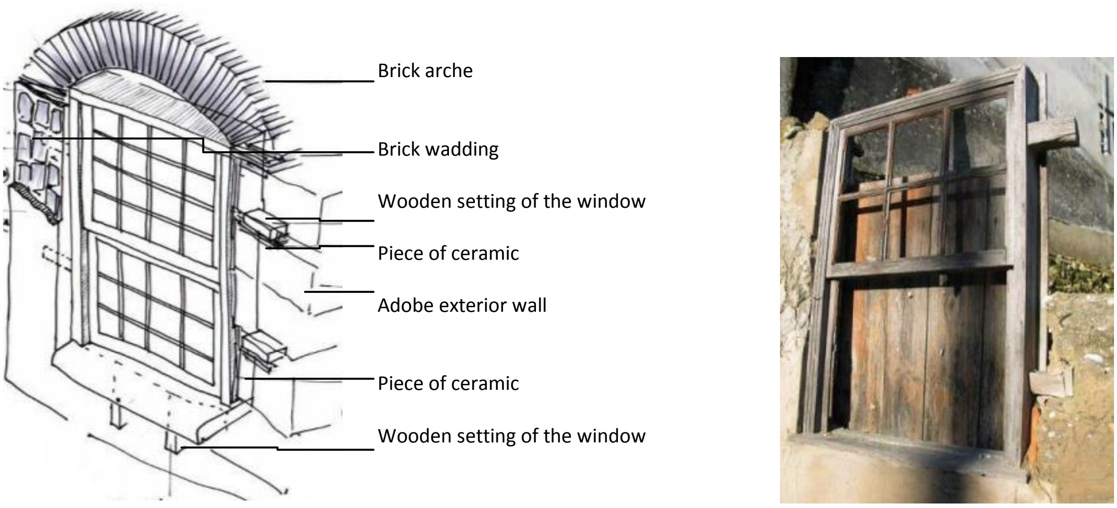

Figure 3-40 – Fixation of opening [credits Alice Tavares]

One of the materials associated with wood is ceramics, as can be observed in the formation of span arches or as a transition element between materials (adobe/timber).

The adoption of 0.02 m thickness of ceramic plates was also applied (i) to reinforce the resilience of stem walls or of other areas identified as less resilient, such as corners, doors and windows columns; (ii) to reinforce and contain wood or metal parts or specific elements of the curtain wall/façade; and (iii) to provide resilience in areas with higher cracking probability due to higher stress concentration. Furthermore, this application of thinner ceramic parts frequently replaced the cross laying of adobes at the prominent upper part of the cornice. The use of solid or hollow bricks for sections of wall underneath windowsills was also observed and was often used to form the arches of lintels of exterior and interior doors and windows (Tavares A et al. 2012-a).

The strengthening of the corner can be observed in Italian rammed earth constructions of Piemonte and in other regions, such as Alessandria. Similar procedures can also be found in the basement of the construction or in rubble masonry in adobe constructions of the central region of Portugal.

The use of solid or hollow ceramic bricks for sections of wall underneath windowsills was also observed and is often used to form the arches of lintels of exterior and interior doors and windows (Tavares A et al. 2012-a). The platbands, whose use became more common after the Art Deco period (at least on the front façade) and occasionally as an element added to older buildings, can also, be made of brick.

Interior walls were normally formed by *tabique*, although in larger constructions, these walls could be made of adobe acting as interior loadbearing walls. However, the timber-framed partition walls gradually ceased to be used during the 1930s and were replaced by brick masonry walls (commonly three-hole brick), closely applied to the cleaver (*assentes ao cutelo*). In 1950, this represented 98% of interior walls.

Other elements, such as ceramic shards (*cacos*), were used to help the cohesion of the thicker filler area associated with the need to render the design of facades with slightly prominent elements, as is usually seen in the edge region of the openings or entrance. A demarcation of some parts of the facade replaced the projections previously given by the stone elements (trims of doors and windows - *guarnições*).

The buildings were painted with lime supplemented with an additive that gave the desired colour. The exclusive use of light colours is usually assumed. Nevertheless, in the region of Ílhavo, a fishing town, strong colours were used frequently and were associated with maritime activity given the proximity to the colours of the ships on which their owners worked. In this way, the colour was a symbolic identifier of the community and reinforced the strong link of Ílhavo with traditional sea activities. Nevertheless, Ílhavo was not the only region that used strong colours (Tavares A. et al. 2011-a). In contrast to what one might think, there was no light-coloured or white hegemony, a situation that was widely promoted after the 1930s during a national debate phase of the Portuguese National Architecture and later during the implementation of urbanisation plans in the 1940s and 1950s. It should be noted that darker colours were more appreciate for the climate conditions of the region.

In specific periods of history, stone elements were used in the oldest buildings as limestone and granite in the most recent ones. This use was mostly in basements and corners and around openings and thresholds. These uses of stone materials were in restricted periods because this was not a continuous process. The reasons for the application of stonework in the adobe construction in this region could be justified by the industry of building material evolution and transportation development as a source of limestone from the south and granite from the north or interior. However, it should be added that the limestone was mainly used in specific periods prior to the early 20th century and granite was used more in the periods at the end of the 19th century until the mid-1930s.

During the 1940s, some buildings did not have adobe walls and used brick instead; however, they used the same construction rationale. That is, the brick masonry walls were resilient and supplemented with reinforced concrete ring beams, with identical configuration to the ones applied previously in adobe. It is concluded that in this first stage the rationale of the traditional system remained; the wall remained as a structural element instead of any other reinforced concrete structure with beams and pillars (Tavares A et al. 2011-a).

Thicker adobe walls (up to double in size) than those of the middle of the 20th century were also found in older constructions. In project plan sections, it was common to see a wall thickness reduction as the construction level increased. These aspects were common to stone masonry buildings of the north or the rubble masonry buildings of the south. The stability of the entire structure was dependent on the walls' thickness. For this reason, the walls' thickness at the attic level needed proper assessment, mostly in cases of higher roof structures. Despite this important issue, it can be observed that after 1950, the thickness of adobe walls was below the guidelines of the Regulation of Aveiro municipality, which regulated the minimal values for adobe construction. This shows the gap in knowledge of the technicians involved in the construction. The regulations (national and regional) distinguished the proposed thickness in relation to their position in the construction – front facade, gable walls, interior loadbearing walls, and partition walls. Different size needs were also distinguished depending on the level of the floor (ground floor or upper floors). The Regulation of Aveiro municipality assumes that adobe construction could only be applied for two-floor buildings, and recommendations of minimal values were presented taking this into account.

The new laboratory tests and in situ tests by the DECivil-UA revealed important results for the mechanical behaviour characterization of the adobe masonry and its elements, adobe blocks and earth mortars, which can be used in the assessment of adobe walls. Because in Portugal there are no guidelines specific to adobe construction, the results of Costa A (2014; 2012; 2007) and Varum H (2006) research provide a reference for the intervention in this heritage.

From the laboratory tests performed by researchers at the University of Aveiro, we can observe that the compression of the adobe masonry presents different values that can be explained by the characteristics of the natural materials used, their size and percentage in the mixture. The adobe masonry is vulnerable to out-of-plane movements, as generally recognized. This is the reason why the connection between two orthogonal walls is so important to evaluate and improve, including the upper level at the links with the roof structure.

An interesting aspect is associated with the evolution of the composition of mortars (Table 3.3) At this point, the regional influences must be taken into account to understand the diversity of solutions used. The following approach focuses on the period after 1940 because the archives database (with a larger number of the identified types of mortars) refers particularly from this period onwards.

Regarding the mortars, criteria were compiled to distinguish between the type of mortar to apply on wall foundations and the mortar to use on exterior walls, on rendering or even to apply to interior walls. The application of hydraulic lime mortars was prevalent in almost all types of foundations during the entire period between 1940 and 1956. A different ratio of materials was applied on the mortar on the outside walls, such as 1: 3 (hydraulic lime: sand) to foundations and 1: 4 (hydraulic lime: sand) in the outer walls of the same construction.

Regarding adobe exterior walls, the most prevalent mortar used during this period was air lime:sand at a 1:3 volumetric percentage (ratio). Particularly since 1945, there was increasing application of hydraulic lime mortar on walls for both adobe and brick walls, with a 1: 4 ratio (hydraulic lime:sand) replacing the previous solution.

It is noted that in some cases, the use of hydraulic lime mortar was applied up to a certain height of the building (as an indication, to 1.0 m in height). In other cases, hydraulic lime was replaced by cement. In some cases, a water-repellent product (rarely identified or just given the brand mark) was added to the cement to apply to the exterior plaster.

Especially after 1945, the addition of cement in lime and sand mortar increased, although it was not yet prevalent in 1950 for exterior walls. Interior walls in this period (1940-1960) were practically all built with brick masonry, and the mortar applied in most of the cases was cement and sand, with the addition of hydraulic lime in some cases or, much less frequently, with just air lime and sand. A growing concern in the establishment of a waterproof barrier, particularly on the transition level of wall foundations and exterior inner walls, led to experimentation with some additional materials. For this reason, in the 1940s, diatomaceous earth was used in rendering mortars of the base of the construction. In some solutions, the constitution of the exterior layer was supplemented with 5% diatomaceous earth, noted as a waterproofing layer that improved the finishing, as will be explained in a subsequent subchapter.

Despite the changes in construction, the mortar applied depended on the support. For this reason, the cement mortars were only used in the interior walls made of brick or even in exterior walls with this material. Thus, is possible to find in the same construction at least two types of mortars: lime mortars for adobe walls and cement mortars for brick masonry. The following table presents the most common solutions and a selection of other relevant information from the Portuguese National Regulation of 1951 as the specific data concerning adobe present in the Aveiro Construction Regulation of 1956. The values presented in these regulations were the minimal mandatory values.

However, with the increased use of brick in the early 1950s, this assumption was no longer the rule, gradually distorting the criteria that had been adopted for earthen construction. In particular, when the second generation of technicians arrived, the mortars were applied more arbitrarily.

Concerning the plaster composition, several solutions were found. The one adopted in VA was lime (*cal churra*)/hydraulic lime/fine sand of the sea with a ratio of 2:1:10. Although the use of sand of the sea improved the work, it introduced salts that can damage the adobe and the rest of inner layers of plaster over time (Figure 3-41). Usually, three layers were applied, diminishing the size of the particles of the materials. At the VA in 1941, the exterior walls were whitewashed and the interior walls painted with the plaster still fresh.

Figure 3-41 – Adobe building with reinforced concrete ring beams [credits Alice Tavares]

WALLS CHARACTERISTICS

	19th CENTURY	20th CENTURY				
		1900-1919	**1920-1939**	**1940-1949**	**1950-1960**	**1951-1956 REGULATIONS**
EXTERIOR WALLS Materials:	Earth/Sandstone Adobe Brick (thin ceramic tiles in complement to the adobe system)	Adobe Earth/Sandstone Brick (thin ceramic tiles in complement to the adobe system)	Adobe Brick (less) Reinforced concrete (RC) elements (punctual)	Adobe – 344/388 Brick – 40/388 30 x 15 x 8 cm / 30 x 15x 15 Cement blocks (ratio 1:7) 3/388 and RC elements	Brick 30x15x8 (include double plan) – 97/315 Adobe – 216/315 Cement blocks - 2/315 RC elements	Stonework or stone irregular – **Sw** or **Si** Ceramic brick (23x11x7 cm) - **Bi** Cement blocks (ratio 1:5 or 1:6) - **CB** Adobe blocks - **Ad**
Common dimensions of adobe blocks	43 x 11 x 29 cm 40 x 11 x 23 cm 38 x 11 x 29 cm 32,5 x 10 x … cm 30 x 10 x…cm	45 x 31 x 13 cm 43 x 30 x 10 cm 42 x 10 x 32 cm	39 x 9 x 32 cm 39 x 8 x 24 cm	40 x 30 x 12 cm 40 x 20 x 12 cm 30 x 20 x 12 cm 43.5 x 10.5 x …cm	40 x 20 x12 cm 30 x 20 x12 cm 40 x 30 x12 cm 40 x 25 x 12 cm 30 x 25 x 12 cm	Non mention for adobe. (23 x 11 x 7 cm for stone or brick)
EXTERIOR WALLS (ADOBE) Thickness: Groundfloor (GF) Uppers floor (UF)	> 1.00 m* > 0.60 m*	> 0.60 m > 0.45 m	> 0.45 m > 0.35 m	0.30 m – 85/122 0.35 m – 23/122 0.40 m – 7/122 Others - 7/122	0.30 m – 138/144 0.25 m – 5/144 0.35 m - 1/144	**Sw**:GF– 0.32 m / UF– 0.28 m; **Si** – 0.50 m / UF- 0.40 m **CB**: GF – 0.30 m / UP – 0.25 m **Ad** (adobe): GF – 0.50 m/ UF: 0.30 m **Ad** gable walls: GF: 0. 30 m / UF: 0.25 m
INTERIOR WALLS Materials (ratio)	Adobe *Tabique*	*Tabique* Adobe Brick	*Tabique* Brick Adobe	Brick Adobe (less) *Tabique* (scarce)	Brick	Stone (stonework or irregular) – Sw and Si Ceramic brick (23 x11 x 7 cm) - B Cement blocks - CB Adobe blocks - Ad
INTERIOR WALLS Thickness		*Tabique* – 0.10 -0.15 m Adobe – 0.30 - 0.35 m	*Tabique* – 0.10 -0.15 m Brick - 0.10 m Adobe – 0.30 -0.35 m	Brick -0.10 m *Tabique* – 0.10 -0.12 m		**Sw**: 0.32 m / 0.28 m; **Si**: 0.50 m / 0.40 m **Ad** (Adobe): 0.25 m
MORTARS OF FOUNDATION WALLS Mmaterials (ratio) Volumetric dosage			1:3 1:5 (VA) + asphalt or tar	Hydraulic lime / sand: 1:2 or 2:5 or 1:3 1:4 (VA) Lime / sand (/ diatom) Sand / cement / diatom	Hydraulic lime / sand: 2:5 1:3 1:2	
MORTARS OF EXTERIOR WALLS Materials (ratio) Volumetric dosage			1:3 (adobe - VA) 1:5 (brick - VA) + asphalt or tar	Lime / sand – 1:3 Hydraulic lime / sand: 1:3 or 1:4 or 2:5 or 1:5 Lime / sand / cement Sand / cement / diatom Lime / sand / waterproof	Hydraulic lime / sand: 1:5 or 2:5 Hydraulic lime / sand / cement Lime / sand / waterproof material	
MORTARS OF INTERIOR WALLS Materials (ratio) Volumetric dosage				Cement/Sand: 1:4 or 1:3 Lime / Cement / sand Lime / Sand Hydraulic lime / sand	Cement / sand: 1:3	

Table 3.3 – Synthesis of walls characteristics [credits Alice Tavares]

3.5. Structure of the floors

This sub-chapter is based on documents of archive files and construction regulations of the Aveiro (1003 files) and Porto (1462 files) regions and in situ surveys in both regions. A synthesis of the research on the materials and cross section used for the structure of floor is presented in Table 3.4, at the end of the sub-chapter.

In ancient adobe buildings, prior to the 19th century, the floors structure was made of regularly spaced round timber beams, and timber floorboards were placed on top of these beams. Despite the lack of written information regarding changes in construction, the ground floor likely did not have traditional timber beams and void spaces for ventilation in the base of the walls, which were common in later periods. It is necessary to conduct more in situ studies to confirm this possibility. Nevertheless, many of the ancient buildings in the region do not have timber at the level of the ground floor. For buildings with two floors, the upper floor was the residential floor, and the ground floor was used for secondary, non-residential functions and, in many cases, was unpaved (only earth). This layout was observed in some Art Nouveau buildings and in many other buildings until the 1930s, as identified through several talks with older people and from cases for which this aspect has not changed. The ground floors are now paved, but this was not necessarily the original state.

In the buildings of the 20th century, the floor structure is typically made of pine, which is fastened/anchored into the wall and often has a base of small ceramic slabs at the support area (Tavares A et al., 2012-a). This improves the resistance of the embedding area of the beams and separates the timber from the eventual contact with rising damp in the wall. In addition, the end of the beams was treated with an anti-xylophages product (*cuprinol/carboníleo*) or, in ancient times, with tar substitute. Occasionally, before the timber beams were placed on the ground floor, other thinner timber beams were applied along the base support walls to help the levelling and to separate the foundation walls from the timber structure above. This allowed better ventilation around the timber beams (floor joists). In Porto in 1913, a similar situation was already reported, with 0.15 m x 0.12 m^2 beams, but in this case, the report focused on stone masonry buildings. The concern about the durability of the timber structure was later reflected in the 1951 Regulation (RGEU). The RGEU mentions that when a structure is wood, it should have an air box with a minimum height of 0.50 m cross-ventilated by circulating air provided by openings in the walls. Of these apertures, those located on the outer walls should have devices to prevent the passage of objects or animals to the extent possible. This solution does not prevent the effect of termites. Nevertheless, this ventilation base was not previously used in all the buildings, particularly because 1920s urban regulations (Porto) imposed only 0.20 m of space between the level of the interior ground floor and the level of the street. When similar regulation was applied in the Aveiro region, it greatly increased the problems of earthen construction in terms of the base decay of the walls and the timber structures of the ground floor. As a consequence, the use of reinforced floor screed (*massame de cimento armado*) for the ground floor was common, and the traditional ventilation space of the base of the walls ceased to exist in the 1950s. Thus, due to the decrease of the ventilated area and its discontinuity across the area of the base, it became difficult to prevent the rising damp in the walls. This often resulted in the presence of efflorescence on the confining walls of these spaces. Recent conservation interventions have experienced difficulties in solving this problem. Nevertheless, the RGEU states that the pavement of the ground floors must rest on a waterproof barrier layer. A similar situation was prescribed during the 1940s urban plans implementation, as a cement base was used throughout the construction prior to the floors being built. In addition, given the pathologies in this type of building, this rule was not sufficient to prevent the problem of rising damp.

The use of billets (*tarugos*) was common practice, as shown in the archive files (Porto) from the 19^{th} century until the beginning of the 20^{th} century. However, after the 1920s, billets are barely mentioned in the written documents of architectural plans.

Thin slabs of reinforced concrete became widely used after the 1930s and were applied especially for terraces / balconies, kitchens, bathrooms, sunrooms (*marquise*) and porches.

Table 5 presents a summary of the main characteristics of the floor structure. It includes the synthesis of data collected from the Porto archives to characterise the period prior to 1940. This region was selected because it had a substantial influence in the Aveiro district. As the choice of timber species for the structure of the floors was not always the same as that for the roof, the conclusions also slightly differ. The *Pinus pinaster* was the first choice beginning in 1900 and became prevalent in Porto after 1920. This was also a popular choice in the Aveiro region starting in 1940. The 0.22 m x 0.08 m^2 cross sections were primarily used in Porto from the end of the 19^{th} century until at least 1939. Nevertheless, in the following periods, thinner cross sections were used in the Aveiro region. This could be associated to a more restricted span in adobe buildings; however, the consequence is shorter values of beam spacing.

In Porto, the spacing of the beams was approximately 0.60 – 0.50 m, while in the Aveiro region, it was 0.50 – 0.40 m. This was in accordance with what is prescribed in the regulations of the 1950s, i.e., cross sections of 0.16 m x 0.08 m^2 with beam spacing of 0.40 m. Finally, after 1940, the lining of the floors was typically made of 0.028 m x 0.10 m^2 or 0.025 m x 0.10 m^2 timber boards in the Aveiro region after 1940.

We observed decreases in the cross section of the joists and their spacing and the change of timber species used until the prevalent pine in the 1950s.

This summary mentions the number of files consulted, the number of files validated for each topic and the number of files that mention the data of each item. A small number of files are validated for each topic because we did not validate files with any type of doubt in relation to the specific topic or item. It also expresses the scarcity of information that was included in architectural projects in some periods.

FLOORS CHARACTERISTICS

	19th-CENTURY*	20th-CENTURY				
		1900-1919*	1920-1939	1940-1949	1950-1960	
					Archive Files	1951-1956 REGULATIONS
GROUND FLOOR	Earth Ceramic bricks or ceramic slabs	Earth Ceramic Floor screed	Timber beams Concrete groundbearing floors slabs	Timber beams Reinforced concrete slabs with bricks Rigid reinforced concrete slab Concrete groundbearing floors slabs	Timber beams Reinforced concrete slabs with bricks Rigid reinforced concrete slab Concrete groundbearing floors slabs	Allow timber floors and concrete groundbearing floors slabs (service areas)
UPPER FLOORS	Timber beams	Timber beams Rigid reinforced concrete slab (thin slabs but scarcely)	Timber beams Reinforced concrete slabs with bricks Rigid reinforced concrete slab	Timber beams Reinforced concrete slabs with bricks Rigid reinforced concrete slab	Timber beams Reinforced concrete slabs with bricks Rigid reinforced concrete slab	Allow timber floors and reinforced concrete slabs
TIMBER SPECIES	**Files Porto** (68/162): Pinus sylvestris– 40/68 Pinus Pinaster – 16/68 Castanea Sativa– 08/68 Pinus rigida – 02/68 Quercus faginea -02/68	**Files Porto** (395/826): Pinus Pinaster – 184/394 Pinus sylvestris – 149/394 Castanea Sativa – 045/394 Pinus rigida – 010/394 Pinus linea L. – 006/394	**Files Porto** (180/474): Pinus Pinaster – 170/180 Brazian timber – 005/180 Pinus sylvestris – 002/180 Castanea Sativa Mill –002/180 Eucaliptus – 001/180	**Files Aveiro district** (125/906): Pinus Pinaster Aiton – 124/125 Eucaliptus Globulus – 001/125	**Files Aveiro district** (39/97): Pinus Pinaster Aiton – 39/39	Non mention.
SECTION OF BEAMS	**Files Porto** (57/162): 0.22 x 0.08 m – 20/57 0.20x0.08 m – 06/57 0.18 x 0.08 m – 06/57 Ø 0.18 m – 06/57 Ø 0.20 m – 05/57 Others (11)– 14/57	**Files Porto** (107/826): 0.22 x 0.08 m – 87/107 0.25 x 0.10 m – 03/107 0.20 x 0.07 m – 03/107 Others (11) – 14/107 0.18 x 0.10 m (in situ- Vila Africana from Aveiro district)	**Files Porto** (58/474): 0.22 x 0.08 m – 49/58 0.25 x 0.08 m – 03/58 0.22 x 0.10 m – 02/58 Others (3) – 04/58	**Files Aveiro district** (56/906): 0.18 x 0.10 m – 19/56 0.18 x 0.08 m – 12/56 0.18 x 0.09 m – 11/56 0.20 x 0.10 m- 07/56 0.18 x 0.07 m – 04/56 Others (3) – 03/56	0.20 x 0.10 m 0.18 x 0.10 m 0.18 x 0.09 m 0.18 x 0.08 m 0.18 x 0.07 m 0.16 x 0.09 m	0.16 x 0.08 m (or equivalent in terms of resistance and rigidity)
SPACEMENT BETWEEN BEAMS	**Files Porto** (46/162) 0.60 m – 22/46 0.66 m – 10/46 0.65 m – 05/46 0.50 m – 04/46 0.40 m – 03/46 Others (2) – 02/46	**Files Porto** (49/826): 0.50 m – 18/49 0.60 m – 15/49 0.55 m - 07/49 > 0.66 m – 04/49 0.65 m – 03/49 < 0.50 m – 02/49	**Files Porto** (10/474): 0.50 m – 05/10 0.60 m – 02/10 Others (3) – 03/10	**Files Aveiro district** (48/906): 0.40 m – 25/48 0.50 m - 18/48 0.45 m – 05/48 0.55 m – 01/48	0.40 – 0.50 m	0.40 m
COVERINGS				Timber slabs: 0.028 m x 0.10 m – 10/11 0.025 m x 0.10 m- 01/11	Timber slabs (0.028 m x 0.10 m or 0.025 m x 0.10 m)	

Table 3.4 – Synthesis of floors characteristics [credits Alice Tavares]

3.6. Typologies of structures of the roofs

This sub-chapter is based on documents of archive files and construction regulations of the Aveiro (300 files) regulations of the Aveiro (300 files) and Porto (1430 files) regions and in situ surveys in both regions. A both regions. A synthesis of this research on the timber species, typologies of trusses and respective spans is respective spans is presented in Table 3.5. A synthesis of the typologies and correspondent cross sections used for each element of the roof structure is presented in

Table 3.6, at the end of the sub-chapter.

In this research, we define three main groups of structure typologies for the roofs based on the previous identification of the principal loadbearing element of the roof structure. In this sense, every time the main support element was the rafter, the adopted name was rafter truss; when it was the purlins, purlins truss; and finally, the more complex structures of trusses were called King-post truss / Palladio truss. As explained in the previous chapter, the examination of Porto is very relevant for the period between 1895 and 1939 and can reveal the tendency that characterised that period. For a better understanding of the 18th century Porto bourgeois buildings and their construction system, readers are directed to the theses of Francisco Barata (Fernandes FB 1999) and Joaquim Teixeira (Teixeira J 2014), which provide valuable information. The current research addresses a later period, when Porto became a reference for the surrounding regions and an increased centre of industrialization. Changes are particular evident in the evolution of solutions for roof structures. In this chapter, the names adopted for the elements of the roof structure are identified in Figure 3-42 Considering the different solutions, some of the elements do not appear in all solutions, namely, in the simplest rafter truss and purlins truss.

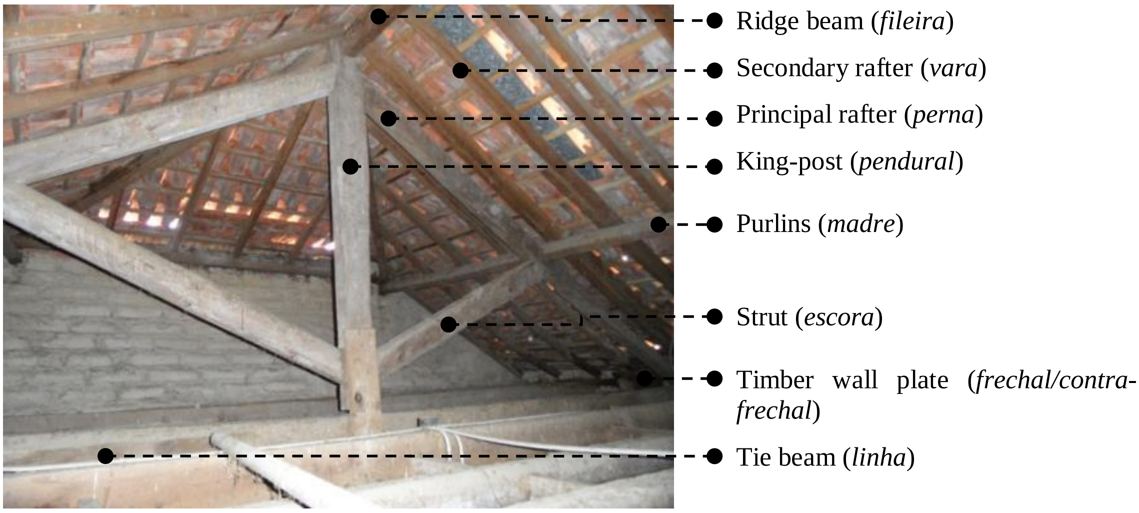

Figure 3-42 – Example of a king-post truss [credits Alice Tavares]

Concerning the timber species used in the roof structures, *Pinus pinaster Aiton* was highly prevalent after 1920 in both the Aveiro and Porto regions (Table 3.5). This is in accordance with the situation previously observed for the floors structure, for which the exchange of choices between *Pinus sylvestris* and *Pinus pinaster* progressively took place in the period between 1900 and 1919. It is also interesting to observe that the use of most common species used prior to the 20th century, *Castanea sativa*, was decreasing. By contrast, the prescriptions for *Pinus pinaster* were strongly increasing. Some other imported species, such as Brazilian timbers and *Pinus rigida*, maintained low levels of application. Nevertheless, in the Aveiro region, this species was used mostly for non-structural elements of construction in particular periods, as assessed *in situ*.

In 1916, the use of two species of wood in the same roof structures was observed. The criterion used to select the species was the best wood (with increased resistance) for the structural elements and the wood with the least resistance to non-structural elements (such as *Castanea sativa* for the principal structural elements and *Pinus pinaster Aiton* for the remainder). The most durable wood was used in the elements that were in contact with the exterior or near, such as the timber wall plate, which can be justified by their close contact with moisture from the exterior walls. This concern to preserve the wood in the best possible condition for a long period of time is also a justification for the use of pillars adjacent to the support walls. In this case, the principal structure of the roof did not need to be inserted into the wall or, at least, was much less embodied. Thus, the tie beam had the necessary ventilation, which in addition to the slightly less span and higher area of support, was relevant to the durability of the structure.

Again, the timber species selection criteria included the level of exposition to weather conditions and the possibility of humidity, as based on proximity to the facades. Thus, the woods species were chosen based on the durability characteristics known at the time. For structural elements, the preferred order was as follows: 1º *Castanea sativa*; 2º *Pinus rigida* or Brazilian wood; 3º *Pinus sylvestris*; 4º *Pinus pinaster Aiton*. The use of eucalyptus in the construction was completely marginal during the study period. In opposition to typical claims, oak was scarcely used for structural elements during this study period in both regions. It is served as a non-structural element, and its dimensions were typically 0.18 m to 0.24 m (diameter) or at most 3.5 m - 5.5 m long in older buildings. Other purlin sections were found as (b×h): 0.14 × 0.22 m; 0.10 × 0.22 m; 0.07 × 0.22 m; 0.10 × 0.20 m; 0.08 × 0.20 m; 0.08 × 0.18 m and 0.06 × 0.18 m. The secondary rafters applied above had a cross section that was often approximately 0.08 × 0.06 m with a spacing of 0.40 m or a cross section that was approximately 0.08 × 0.05 m with a spacing of 0.35 m.

Another interesting aspect that should be emphasized is the attitude of the technicians at the time concerning the conservation processes or changes to construction, as they valued the materials recycling, namely, wood. Materials were recycled not only to diminish the cost of construction but also as a recognition of the better quality of the old timber in terms of resistance to decay, mechanical behaviour, and the guarantee of a complete drying process with less tendency of deflexion. For these reasons, references to the re-use of old timber beams of *Castanea sativa* are commonly found. As an example of re-used materials, we present a short transcription of two documents that belong to architectural archive files (from Porto) and show two different situations. The first file, from 1916 (nº 722, ACI Porto), said "For the construction of this building, all the materials from the demolition of the current buildings of the same owner or holding that are in good condition will be used for our project". The second file, from 1920 (nº 244 ACI Porto), was written by architect Júlio Brito, who said: "the roof truss will be the same, as it will maintain the same shape; but we shall be careful to examine and replace the timber parts that are not in good condition". Both transcriptions show that the architectural design valued the economy of materials, the reduction of debris, the reasonable idea of not making changes simply to have all new materials, as observed in the present time, and the maintenance of the shape if the function was the same. Moreover, the cost of labour as likely also taken into account, as new carpentry work with *Castanea* was assumed to be more laborious than work with *Pinus.* Working with existing parts, particularly with the first type of timber, saved long work hours.

The *Pinus* was widely present in this sample of the Aveiro region, which illustrates its major presence after the 1940s; however, it cannot be assumed that only this species was used. The Eucaliptus application on roof structures was observed in *in situ* assessments of construction built after the 1950s. In this particular situation, there were round section elements that were almost uncut and mostly used for tie beams and purlins.

In the beginning, the gradual use of reinforced concrete for manufacturing factories was endorsed by the Porto Town Council and justified by the need for fire control. Several changes began to be applied first to industrial construction and warehouses and later to housing, including the introduction of reinforced concrete and the widespread use of brick for the entire construction. In many cases, this resulted in the substitution of the proposed timber roof structure for a reinforced concrete solution, as observed in existing buildings during the process of approval of the architectural plans. Nevertheless, this substitution was progressively slower for dwellings, which represented the larger proportion of buildings under construction.

In this research, we identified the following main timber trusses of the roof of adobe buildings.

- rafter truss (Solution RT);
- purlins truss (Solution PT);
- triangular truss (Solution T);
- king post truss with double ties without struts (Solution KPDT);
- king post with struts (Solution KP);
- asymmetric truss (Solution AT);
- special truss with extra support (Solution STS).

3.6.1. The simplest timber structures of the roof – the rafter and purlins trusses

The two simplest structures – rafter truss and purlins truss – reveal the expedited way to solve the problem of roof with fewer means or less technical expertise, according to available local materials, the stage of industrialization, and traditional construction practices. This would promote easier assembly methods that could be applied faster and with minimal timber waste. Typically, the roof trusses with these typologies present one or two slopes and, in less frequent cases, with three or four slopes, with 26º to approximately 35º.

The common **rafter truss** (Figure 3-43) with tie beams is likely to be the most common configuration throughout Europe, namely, in the South, and it is associated with the need to reduce the extension of the timber pieces and to simplify the transport and construction process (Leonardo da Vinci Project 2008), even if this hides a great variety of sub-typologies (Szabó, 1998). To understand the variations, first, the principal configuration of a rafter truss should be properly characterised. It is a very simple structure with pairs of common rafters that typically lean against each other on the top of the roof, in regular spacing, commonly approximately 0.30-0.40 m. The section of the timber elements of this structure is nearly the same for every part. This favours the optimization of the use of timber pieces. Although it is assumed to be a widespread solution, it was not highly prescribed based on the database archive files. Nevertheless, such solutions were observed in *in situ* surveys, primarily for secondary constructions. This may be because it is an older system that was primarily applied prior to the analysis period in discussion.

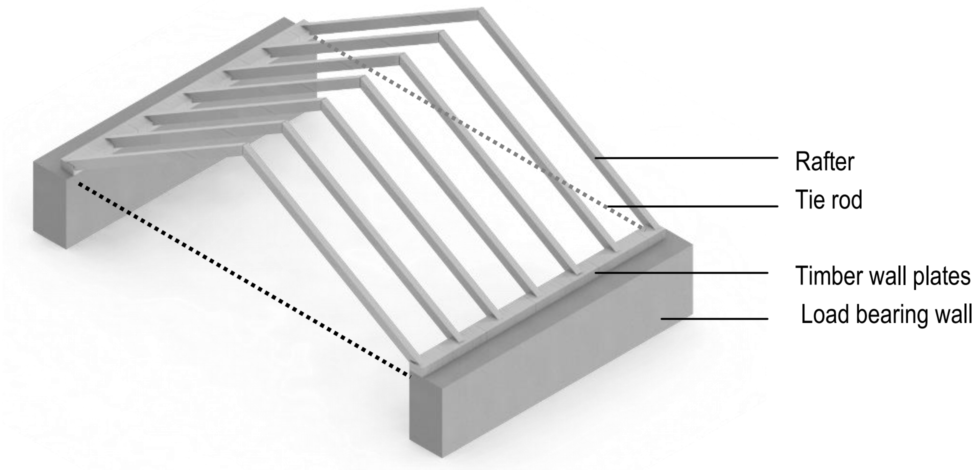

Figure 3-43 – Rafter truss [credits Alice Tavares]

The stability of this type of structure depended particularly on two important complementary elements:

i) a tie rod (*tirante*), a spacing usually 3.0 – 4.0 m, to counteract the tendency of overturning of the walls imposed by the rafters due to the result of horizontal thrust, a tendency when the rafters are not functioning well. This reveals the importance of the connection between timber wall plates of opposite walls through metal or timber tie elements;

ii) timber wall plates (*frechal*) in each opposite wall (where the rafters are usually connected by a lap dovetail). The identification of the wall plates is frequently neglected in architectural design plans, despite their fundamental rule in the global structure (roof/walls). These last elements are important because they receive the loads from the rafters and transmit them to the walls and maintain the position of the rafters. Due to the reduced spacing of the rafters, the distribution of roof charges could be more uniform in cases of proper dimensioning and configuration, which was a positive aspect for the stability of the whole structure. In this typology, it should be considered that the load of the roof tends to impose some deflections to the rafters. To control this situation, the relationships among dimension, design, spacing and length of the elements needed to be assessed. However, it has limitations in terms of the spans that must be overcome. For this reason, its use in larger buildings presents some variations. The use of intermediate supports, such as walls, thereby counteracted its original structural behaviour and main characteristic. In other cases, the rafters are also connected with the *tabique* walls and if done well, can improve the global behaviour of the structure (Tavares A et al., 2013-b). Most solutions presented a cross section of 0.10 x 0.10 m2 with spacing between 0.25 m and 0.35 m.

The observed variations in rafter roofs generally maintained the simplicity of the typology and primarily had three main objectives:

- increasing the rigidity and durability of the apex of the roof using short collar ties in regular spacing to connect pairs of rafters near the apex;

- increasing the bracing and maintenance of the proper alignment of the apex through the use of thin ridge boards in the apex with a piece with 0.03×0.12 m2 (bxh), including the addition of short collar ties (Figure 3-44);

- diminishing the tendency of deflection of the apex through intermediate support elements, such as short walls or timber plumbs, sometimes supplemented by a thin timber plate with 0.10 × 0.025 m in a horizontal position resting above the support elements.

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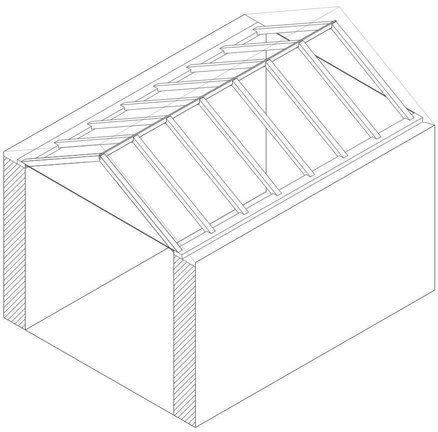


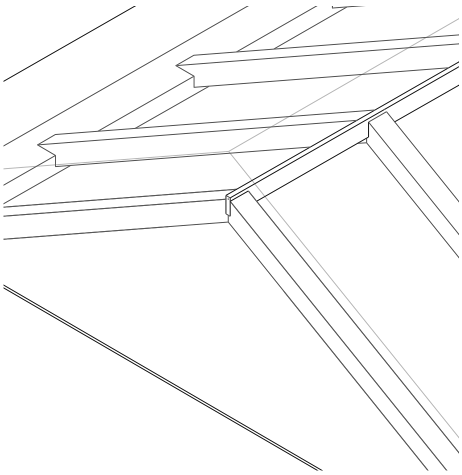


Figure 3-44 – Use of a timber element to maintain the alignment of the apex in a rafter truss [credits Alice Tavares]

The database analyses show a great decrease of the use of rafter systems during the 20th century due to the following factors: changes in the configuration of the buildings, a deeper knowledge of the vulnerability of the system and of decay effects, and the progressive industrialization of the construction components, resulting in increased confidence in more complex solutions.

This was a typical solution for roof structure in ancient traditional construction and, for this reason, does not have a reported number in the database (1895-1939) given the growing number of engineered solutions.

The **purlin truss** (Figure 3-45) is characterised by the use of timber beams (purlins) supported on the walls or on vertical props that the secondary rafters support. The number of purlins used was dependent on the span. The spacing of purlins was commonly 1.8 - 2.5 m. The purlins were usually positioned as follows: one at the top of the roof as a ridge beam and two, four or more other purlins dividing the slope of the roof in approximate identical parts, including one on the upper part of the walls, such as a timber wall plate. This solution was dependent on the distance of the loadbearing walls that supported the purlins. It was also dependent on the orientation of the apex, which involved different spans, or on the distance between opposite gable walls. The most ancient constructions present round section purlins, frequently complemented by support struts due to the longer distance between the support walls and possibly to control deformations. These timber elements were frequently uncut, requiring the use of nails (manufactured, during the 18th century) that were 0.01 m thick to connect the timber elements to guarantee the proper transmission of loads.

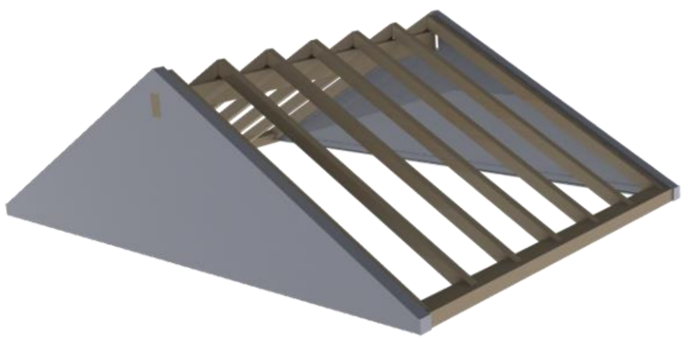


Figure 3-45 – Purlins truss typology [credits Alice Tavares]

The length of the purlins was appropriated for easier transport and application in the current practices of the time. The restricted dimensions of the buildings allowed the use of this type of structure without many risks of the deflection of the pieces with the usual cross sections. However, the later decrease in its use for housing could be justified as a side effect of changes in a more industrialised construction and, again, greater confidence in more engineered solutions. This became almost irreversible during the 1930s in both Porto and Aveiro. Additionally, one should remember the impact of the decreased thickness of the walls on the upper floors and their material changes. The requirement of this system, which imposes loadbearing interior walls or support elements until the coverage level with restricted spacing, should be considered. This was counter to the increased interest to take over the interior space using thin walls with lower costs, resulting in the diminished use of the system. Moreover, one should consider the changes in the urban planning land of the territory promoted through the new urban legislation of 1934 (as General Urban Planning for the locals with more than 2500 inhabitants) and the subsequent legislation of 1938 for this same matter. The urban plans of this period introduced changes in the division of the land, mainly involving the greater width of urban parcels, which implied an increase in the width of the construction of dwellings and multifamily housing. In addition, some new architectural designs introduced technical difficulties because they were generally not easily compatible with the traditional solutions. Again, the national regulations or guidelines of the municipalities had effects on the construction, namely, the gradual substitution of the timber trusses for reinforced concrete solutions.

The observed variations in purlin trusses (Figure 3-46) predominantly have the following two purposes (despite the different solutions to achieve the same objectives):

- Adapt the truss typology to bigger roofs (at times, so that the attic could serve as another living space) with larger spans through the addition of spacing struts or plumbs or pillars to support intermediate purlins or even the ridge beam. Frequently, these new support elements were placed below in the alignment of the loadbearing walls or reinforced partition walls.

Figure 3-47 shows a more complex purlins solution with a set of timber pillars and struts (at the corner) usually placed at a distance of 1.0 - 1.5 m from the exterior walls and above the load bearing masonry walls of the lower floor (Tavares A et. al. 2013-b). The pillars are two vertical timber plates that are bolted together to a horizontal timber element connected to the nearest wall at a distance of 2.0 - 3.0 m from each other. The horizontal element is used to maintain the equilibrium of the pillar’s system. The uniqueness of this system is the use of these timber pillars in substitution of load bearing walls at the level of the attic. In addition, the exterior walls received much less loads than the common solution (Tavares A et al 2014). This is an important transition structure in the evolutionary process that could be assumed as an assay for the special solutions of trusses (STS). Despite this, the cases in which the purlins support thinner walls of the attic revealed problems, namely, stress concentration in the embedding of the purlins due to the surpass charge capacity of the wall.

Figure 3-46 – Different solutions to help the support of purlins [credits Alice Tavares]

Figure 3-48 shows another variation with a mixed system of earthen columns with stakes to support the purlins, increasing the height of the interior space available for storage. This was a desire that lead to the adoption of more complex solutions of trusses (STS) in factories and warehouses.

Figure 3-47 – Additional support elements at a complex purlins truss

The purlins truss did not disappear during the 20th century, and they were frequently applied in situations with no long spans, such as in urban areas. This could be justified by the fact that this simple structure had some advantages in comparison to the older solution of rafter system and needed less skill than the king-post truss. Namely, it was easier to maintain the stability of the structure; hence, it tended to be more durable, and the purlins could act as tie beams for the opposite walls if well connected to them, thereby playing a positive role in the behaviour of the entire construction. Another interesting aspect is that the section used in the purlins was usually exactly the same as that used for the beams of the floors and, again, this facilitated the process and management of construction, resulting in faster supply and construction.

Generically, the choice of one system over the other (besides the restriction of span) was based mainly on the presence or absence of load bearing walls in the attic (or roof void) or at least at its floor level. If transversal load bearing walls (stone or earthen masonry) were present in those areas or the distance between the gables walls did not exceed 6 metres, a purlin roof was likely adopted. However, if the partition walls were of timber-framed structure, a lighter solution, such as the use of rafter roofs, was more likely applied

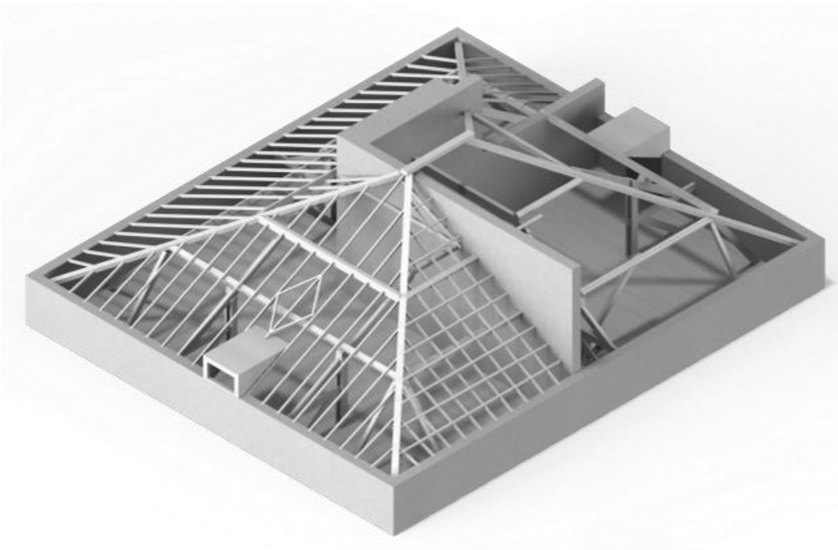


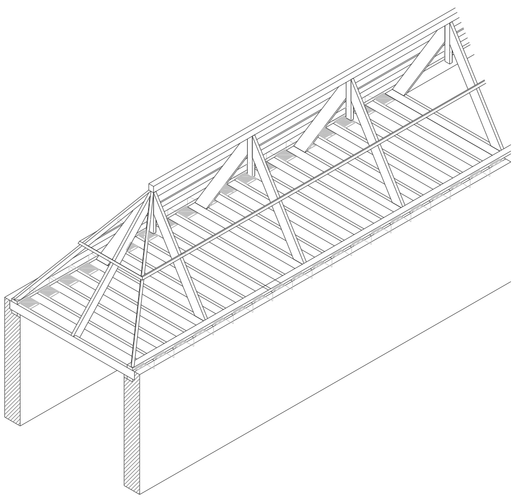
Figure 3-48 – Complex solution of purlins truss [credits Alice Tavares]

3.6.2. Typologies of timber trusses in adobe buildings

The main timber trusses typologies identified and analysed in this research belong mostly to dwellings and a few small industries and warehouses. The buildings had one to four floors and typically a roof of two to four slopes with 26º to 30º. Nevertheless, other solutions with near 45º were also addressed, likely due to the use of the attic for secondary living functions, without largely increasing the height of exterior walls to remain in compliance with urban rules in relation to the continuity of the height of the building along the streets.

Again, the cross sections of the principal pieces of the roof structure were frequently the same as those adopted for the beams in the floors. However, it was concluded that the tie beam could have a higher cross section, particularly in three situations: when the span is higher than 7.0 m, when it supports partition walls of the attic, or when it is connected to the partition walls of the floor below. This structure was already present in buildings in 1915 and could be used in the assessment and identification of the alignments of old partition walls that were demolished in the meantime.

Solution T (Figure 3-49**) -** A very simple truss with just a triangular set composed of a short king-post, principal rafters connected by a nailed lap dovetailed to the king-post and a tie beam at the level of the floor of the attic as a joist. There were typically five roof purlins: a ridge beam, two others at the middle span of the rafters and two as timber wall plates. The slope of this type of roof structure is usually more than 30º for a two or four slope roof. It was a very common solution in old houses, in both regions, mainly until the 1930s and was sometimes confused with the traditional rafter truss. Nevertheless, the difference is easy to observe, as the rafter truss always maintains the same cross section of the elements (rafters). By contrast, Solution T has principal rafters with a higher cross section and secondary rafters with a much lower cross section.



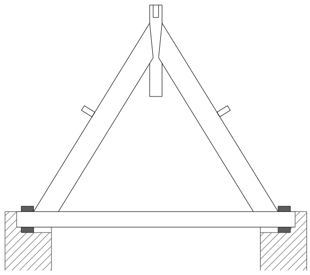


Figure 3-49 – Solution T (basic triangular truss) [credits Alice Tavares]

To oppose the possible rotation of the truss due to its shape and high distance between the short king-post and the tie beam, with almost 45º of rafter slope, the existence of elements that can restrict movements at the apex is rather relevant. This restriction of movement is attained through diagonal rafters from the corners and a rafter at the middle span of the roof. The lack of these elements or their decay will likely lead to truss overturning, compromising the entire structure's stability. A good connection between the purlins and the principal rafters is essential in this type of solution to counteract any movement of overturning the structure. In addition, the top sides of the roof should have the necessary elements to prevent the rotation of the structure. The king post in this typology is usually a short element; nevertheless, in taller solutions with almost 45º of roof slope, it must be a bit longer to guarantee the stability of the structure.

Solution KPDT (Figure 3-50**) -** The main characteristic of this solution is the use of double ties. The truss presents a collar tie placed in the mid-point of the principal rafters or even at a slightly higher level, where the connection of the roof purlins is also placed, allowing the correct distribution of the loads. The king-post is connected to the shorter collar tie in an upper level, slightly increasing the rigidity of the upper part of the structure and restricting the deformability of the rafters. The system uses iron anchors to connect this element to the load bearing wall, which improves the behaviour of the whole construction. Some cases presented a tie beam with a small cross section for the span; the piece tended to deflect due to self-load/weight.

This solution was common for adobe buildings in the period between 1920 and 1935 and was much more frequent than the king-post truss used in Porto during the same time period. One of the underlying reasons is likely its better adaptation to allow the attic to be used as a living space, in the area of the truss; the lower element of the collar tie was almost at the level of the lintel of the doors. The height of the attic is high enough to allow secondary living functions. Although there are some differences, this solution has similarities with the queen-post truss used in the rest of Europe for the same purpose. It is interesting to observe this distinction between the two regions, as KPDT was likely considered more appropriate for adobe buildings. Nevertheless, with time and the increase of industrialization or greater influence of Porto, it was substituted by the king-post during the end of the 1930s.

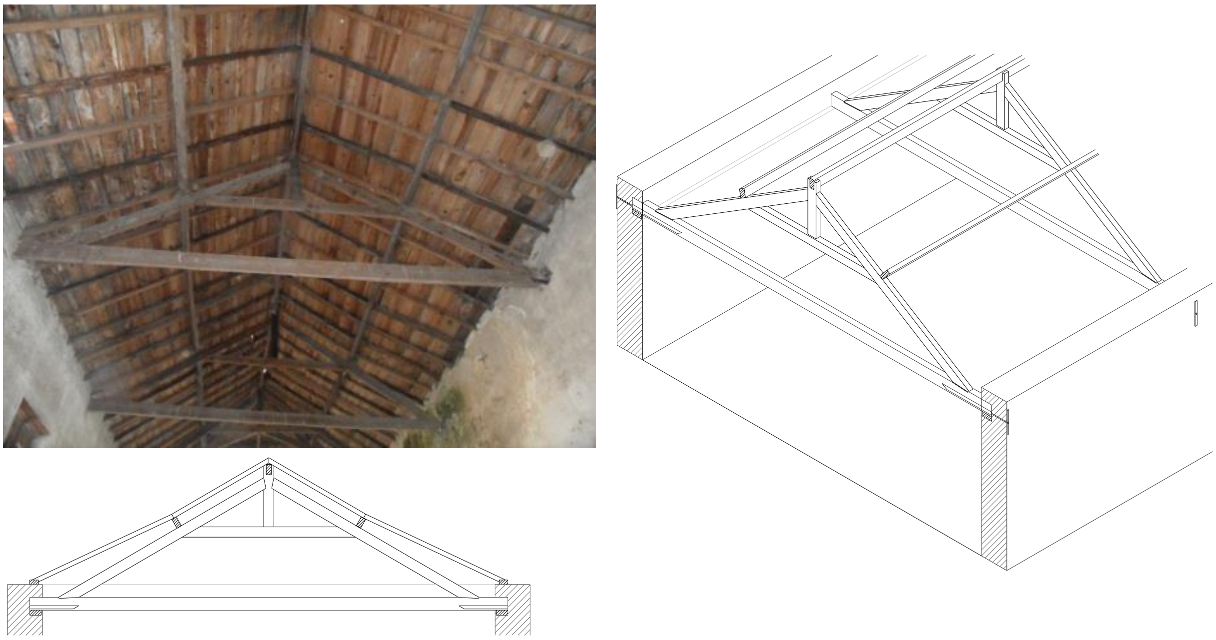
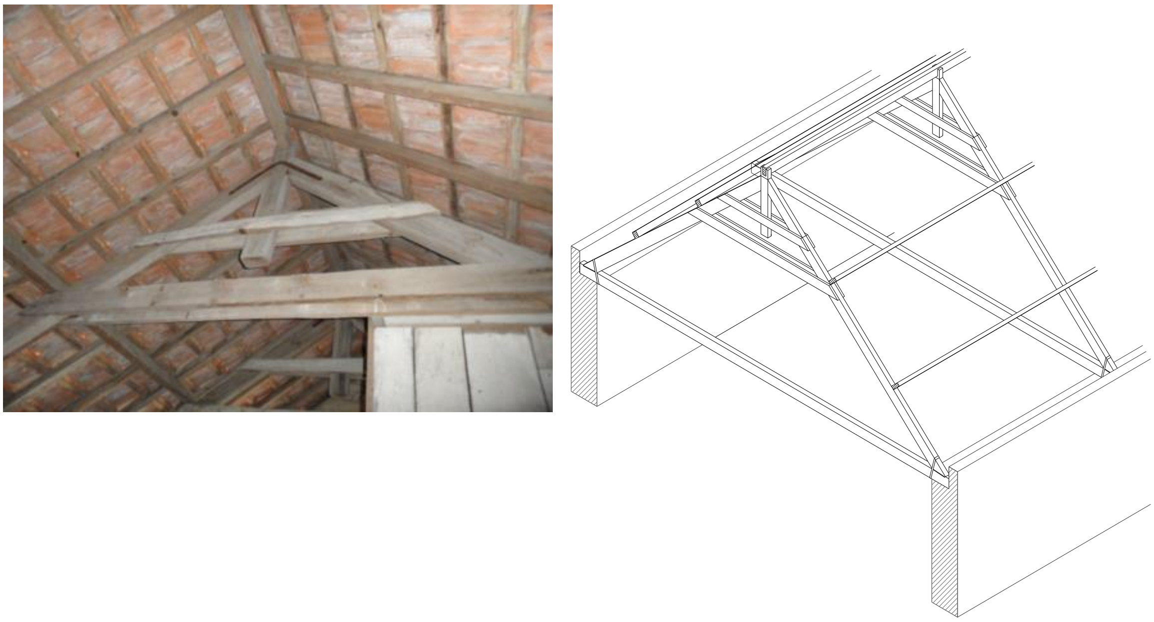


Figure 3-50 – Solution KPDT - king post truss with double ties without struts [credits Alice Tavares]

Figure 3-51 represents a variation of this typology using double pieces for the upper collar ties through the use of double planks; additionally, metal devices are used to connect rafters/king-post and rafter/tie beam.



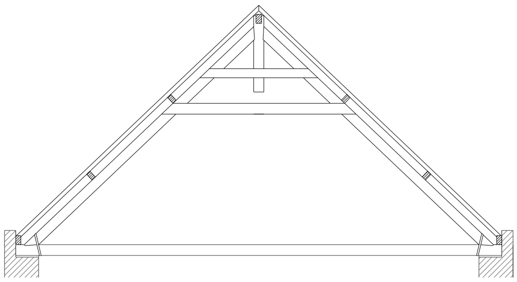


Figure 3-51 – Solution KPDT - example of a king-post truss without struts and with double collar ties [credits Alice Tavares]

The roof span and the height of the ridge beam can impose higher loads on the rafters and overturning movements through them to the walls. For this reason, the use of collar ties at two levels has the objective of restricting the deflection of the rafters but also increasing the stiffness of the upper part of the structure.

Solution KP (Figure 3-52**)** - The king-post truss is a very common solution characterised by a triangular system that is composed of principal rafters connected on the upper level to the king-post and at the lower level to the tie beam (chord). Some solutions present double timber wall plates, one below and another above the lining at the end of the tie beam. This tie beam can be at the level of the attic floor or above it. Two struts connect the king-post to the principal rafters. The common solution uses purlins with the following arrangement: one at the top of the king-post as a ridge beam, two or four dividing the rafter span in similar dimensions at both sides of the principal rafters and two timber wall plates in connection with the wall. In addition, timber block pieces are usually placed with nails to hold the roof purlins in the correct position.

Figure 3-52 – Solution KP - example of a king-post truss and example of longitudinal struts to help bearing the apex [credits Alice Tavares]

The behaviour of a structure depends on the proper role of each element. In this case, the common king-post is in tension while the two struts connecting the king-post to principal rafters are in compression. It should be highlighted that the tie beam plays an important role in counteracting the outward thrust imposed by the principal rafters, offsetting the horizontal force. The heel joint of both elements (tie beam and timber wall plate) is also relevant in ensuring the stability of the whole construction.

In proper configurations, the purlins are at the level of the joints of the struts with the principal rafters, resulting in a better load distribution.

The range of elements and connections of the king-post solution has the purpose of decreasing the stresses in truss members, which gives higher relevance to the joints. The type of joints imposes some differences on the performance of the whole structure; thus, the design and state of conservation of the joints should also be assessed. This type of structure was used in Porto at least at the end of the 19th century, but in Aveiro, it became a prevalent solution after 1940.

Solution AT (Figure 3-53) – This roof structure was usually used for one slope roofs. Although it was more connected with industrial buildings and small warehouses, it was used for buildings with secondary functions, such as garages, porches and other structures complementary to dwellings. It typically presented a set that was similar to that of a half king-post truss with a gentle slope. Its presence in the database is limited due to the type of buildings. Nevertheless, it was considered in the study.

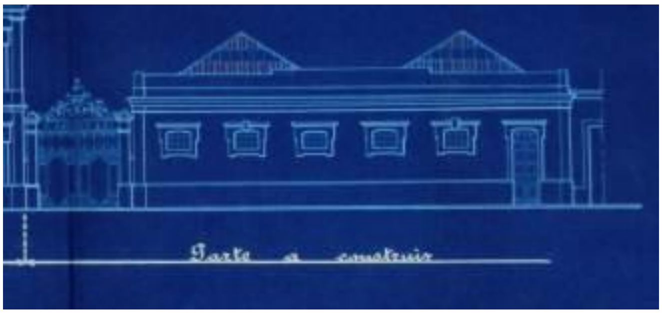


Figure 3-53 – Solution AT – asymmetric truss [credits Alice Tavares]

Solution STS (Figure 3-54) – This solution is more complex and reveals external influences, namely, from France. It was used in palaces, churches, and chapels due to its good adaptation to cover domes. For housing, the required increase in height to use the attic as a normal living space introduced a better engineered timber truss that was designed to be self-equilibrated and minimize the thrust on the walls. Additionally, a larger number of connections could improve the distribution of loads. However, the timber ties connecting the feet of the timber trusses at the level of the attic floor must be properly connected and well preserved. There were two slightly different solutions (STS) for the same purpose of increasing the last floor height, but both solutions have a special set lining against the wall to support the rest of the structure. The difference between them is that one (STSa) uses diagonal struts, and the support area is above the base of the wall (usually exterior wall), and the other (STSb) uses a set of horizontal and vertical poles, diminishing the span. This last solution is used for higher spans (mostly more than 6.0 m) and usually needs load bearing walls to be vertically aligned at the below level to serve as the support of the roof structure above. This solution was used in large dwellings and palaces in the Aveiro region. In Porto, the first (STSa) solution seemed to be more frequently used than the second (STSb) solution, mostly in large dwellings, some hospitals and chapels. Nevertheless, even within each sub-typology, there are some variations, primarily in the connection with the support element but also at the top level of the truss. The different arrangements were dependent on the span of the truss and eventual restrictions of the support elements below.

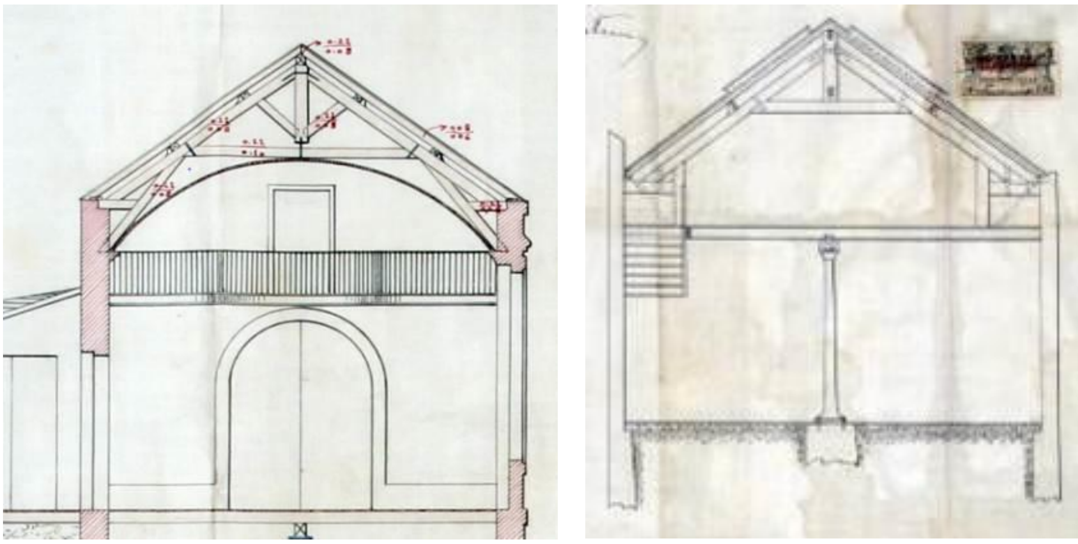


Figure 3-54 – Solutions STS (a and b) – examples of special truss with extra support [credits Municipal Archive Porto and Municipal Archive Aveiro]

The insertion into or close contact of part of these structures to the walls revealed some problems of durability and cracking of the walls due to less confinement of the walls with lower thickness. The negative effects of the wind on these higher structures should also be considered, as they can explain some stability problems when the structures are not in good condition of conservation or properly built. Although STS (a /b) were used for high level buildings such as small earthen palaces, they were also used in common urban houses with the difference of a lower set at support area. Nevertheless, they represent 11.3% of the total validated files of the database. In the Aveiro region, STS was present during the 1920s and 1930s. The *in situ* surveys showed that this solution was also applied in later periods (storehouse) due to the possibility of having almost two floors with a front facade with only one floor. It was a way to surpass urban regulation restrictions and have higher construction density.

Finally, this research presents a synthesis of all the roof structure solutions, divided into three tables: one with the information about timber species, type of solutions and correlating with span; another with the information of the cross section of each element that composes the truss and their timeline use, including data regarding regulations; and one with a summary of the cross section of the rest of the elements – secondary rafters and their spacing and the data of regulations.

As shown in Table 3.5, until 1919, the most commonly used solutions were the purlins truss and king-post truss. The in situ assessment of the Aveiro region buildings shows a predominance of purlins trusses for the same period. For the period after 1920, we assumed the set of values (Porto + Aveiro), which resulted in 655 archives files that were validated for the characterization of the correspondence between roof structures typologies with their span. The main conclusions are as follows:

the scarce number of rafter trusses (RT) show that for this period, the use of this truss was declining;

- the use of purlins trusses (PT) was mostly for spans between 3.0 m and 6.0 m (higher number for 5.1 – 6.0 m);

- the king-post truss (KP) was mostly used for spans between 4.0 m and 7.0 m (higher number for 6.1 – 7.0 m), although it also was used for higher spans above 9.10 m (with metal devices);

- the truss with double collar tie (KPDT) was mostly used for spans between 5.1 m and 8.0 m (higher number for 6.1 – 8.0 m). It is also very versatile and used for higher spans, in this case, with metal devices connecting the structure to the wall.

- The special truss with struts (STS) present mostly two different situations: a variation (STSa) was mostly used for spans between 4.1 and 6.0 m and the other solution was mostly for 6.1 – 8.0 m (STSb). The use of STS was not found for spans above 9.0 m, which can be justified by the complexity in maintaining the structural stability in higher spans.

- The solutions used for higher spans were KP and KPDT.

Table 3.6 shows the cross section of each element of the truss across the study period. Once again, the data from Porto for the period of 1895-1939 were used to determine the basis of influence for the Aveiro region.

From these analyses, it can be concluded that throughout this period in Porto, the main cross section used was 0.08 m x 0.22 m^2, and it was used in more than one element of the truss. The main difference is associated with the higher cross section of the tie beam in some cases (as previously explained). The smaller cross section was used for the elements: struts, timber wall plate and, in some cases, the ridge beam. Over time, there was also greater uniformity in the dimensions of the cross sections used in roof trusses, leaving the range of the 19th century.

In general, the cross section of the elements in the Aveiro region after 1940 is smaller than that used in Porto in previous periods. The smaller sections can be associated with the shorter spans of the adobe construction, which was maintained until the 1950s despite the change in the architecture.

The most common solutions in the database were the KPDT - king post truss with double collar ties without struts (38%) and the current KP - king-post truss (21.8%).

Concerning the secondary elements - rafters and slats (*ripas*) - Table 3.7 summarizes some of the values found. The type of cross section throughout the period shows the prevalence of adaptation to Marseille roof tiles. Nevertheless, this was below the recommendations of the Regulations of 1950s. In addition, the spacing values were below those noted in that Regulation.

The Marseille roof tiles were also frequently used in the Aveiro region despite the ancient type of *canudo* tiles maintained. The edges were often made with *canudo* tiles.

20th CENTURY								
1920-1939			**1940-1949**		**1950-1960** (1951-1956 REGULATIONS)			
Files Porto (141/474): Pinus Pinaster – 135/141 Brazilian timber – 003/141 Pinus sylvestris– 001/141 Castanea Sativa– 001/141 Eucaliptus – 001/141			**Files Aveiro** (100/217): Pinus Pinaster – 100/100		**Files Aveiro** (83/83): Pinus Pinaster – 83/83			
SPANS OF TRUSSES (PORTO AND AVEIRO DISTRICT)								
Nºsolutions (655 Total)	**Under 3.0m**	**3.0 m – 4.0 m**	**4.1 m – 5.0 m**	**5.1 m – 6.0 m**	**6.1 m – 7.0 m**	**7.1 m – 8.0 m**	**8.1 m – 9.0 m**	**Above 9.1m**
04/655	2	0	1	1	0	0	0	0
55/655	1	13	15	21	4	0	1	0
116/655	4	38	44	22	7	1	0	0
143/655	0	6	24	37	27	19	11	19
249/655	0	11	23	46	68	72	19	10
74/655	2	6	19	18	9	15	5	0
7/655	1	1	1	2	0	2	0	0
4/655	0	0	0	1	0	2	0	1

STRUCTURE OF THE ROOF - CHARACTERISTICS		19th CENTURY*	
			1900-1919
	TIMBER SPECIES	**Files Porto** (80/130): Pinus sylvestris– 55/80 Pinus Pinaster – 19/80 Castanea Sativa– 04/80 Pinus rigida – 02/80	**Files Porto** (304/826): Pinus Pinaster – 145/304 Pinus sylvestris– 120/304 Castanea Sativa– 021/304 Pinus rigida – 009/304 Pinus linea L. – 006/304
	TIMBER TRUSSES	**Number of Solutions** (42/68)	**Number of Solutions** (73/304)
	Rafter truss - RT	*0*	2
	Purlins truss - PT	17	11
	Solution T	2	7
	Solution KP	17	41
	Solution KPDT	1	5
	Solution STS	4	3
	Solution AT	1	4
	Solution DCT	0	0

Table 3.5 – Synthesis of timber structures of the roof and timber species [credits Alice Tavares]

20th CENTURY			
1920-1939	**1940-1949**	**1950-1960**	**1951-1956 REGULATIONS**
Files Porto (61/474) 0.22 x 0.08 m – 45/61 0.22 x 0.10 m – 06/61 0.30 x 0.10 m – 03/61 Others (6) - 07/61 **Files Aveiro district** 0.20 x 0.10 m	**Files Aveiro** (5/217) 0.28 x 0.12 m 0.20 x 0.14 m 0.18 x 0.10 m 0.18 x 0.09 m 0.15 x 0.07 m	**Files Aveiro** (1/83) 0.18 x 0.09 m	
Files Porto (28/474): 0.22 x 0.08 m – 20/28 0.22 x 0.10 m – 04/28 Others (4) - 04/28 **Files Aveiro district** 0.20 x 0.10 m	**Files Aveiro** (4/216) 0.26 x 0.12 m 0.18 x 0.08 m 0.16 x 0.08 m 0.15 x 0.07 m	**Files Aveiro** (1/83) 0.16 x 0.08 m	
Files Porto (17/474): 0.22 x 0.08 m – 13/17 0.20 x 0.10 m – 02/17 Others (6) - 02/17 **Files Aveiro district** 0.20 x 0.07 m 0.16 x 0.08 m	**Files Aveiro** (5/216) 0.20 x 0.12 m 0.18 x 0.08 m 0.14 x 0.14 m 0.14 x 0.07 m 0.10 x 0.07 m	**Files Aveiro** (1/83) 0.10 x 0.07 m	0.16 x 0.08 m – spacing of 2.0 m
Files Porto (14/474): 0.22 x 0.08 m – 08/14 0.22 x 0.10 m – 04/14 Others (2) - 02/14	**Files Aveiro** (4/216) 0.20 x 0.12 m 0.18 x 0.10 m 0.18 x 0.08 m 0.16 x 0.08 m	**Files Aveiro** (1/83) 0.16 x 0.08 m	
Files Porto (06/474): 0.22 x 0.10 m – 03/06 Others (3) - 03/06	**Files Aveiro** (1/216) 0.12 x 0.08 m		
Files Porto (07/474): 0.22 x 0.10 m – 03/07 Others (4) - 04/07 **Files Aveiro district** 0.18 x 0.08 m	**Files Aveiro** (4/216) 0.18 x 0.08 m 0.16 x 0.08 m 0.14 x 0.07 m 0.12 x 0.08 m	**Files Aveiro** (1/83) 0.16 x 0.08 m	
Files Porto (03/474): 0.22 x 0.08 m – 01/03 0.16 x 0.10 m – 01/03 0.10 x 0.08 m – 01/03	**Files Aveiro** (2/216) 0.12 x 0.07 m 0.10 x 0.10 m		

TIMBER STRUCTURE OF THE ROOF - CHARACTERISTICS

SECTION OF THE TIMBER ELEMENTS:	**19th CENTURY*** **Files Porto** (130): Hxb – nº/total nº files	**1900-1919**
Tie beam (TB)	**Files Porto** (62/130): 0.22 x 0.08 m – 22/62 0.20 x 0.08 m – 13/62 0.22 x 0.10 m – 08/62 0.22 x 0.07 m – 05/62 0.18 x 0.08 m – 05/62 Others (7) - 09/62	**Files Porto** (87/304) 0.22 x 0.08 m – 67/87 0.25 x 0.10 m – 04/87 Others (12) - 16/87
Principal rafters (R)	**Files Porto** (49/130): 0.22 x 0.08 m – 14/49 0.20 x 0.08 m – 10/49 0.18 x 0.08 m – 08/49 0.22 x 0.07 m – 05/49 0.22 x 0.10 m – 03/49 Others (7) - 09/49	**Files Porto** (78/304): 0.22 x 0.08 m – 61/78 0.22 x 0.10 m – 04/78 Others (10) - 13/78
Purlins (P)	**Files Porto** (85/130): 0.22 x 0.08 m – 29/85 0.18 x 0.08 m – 19/85 0.20 x 0.08 m – 11/85 0.22 x 0.07 m – 07/85 0.22 x 0.10 m – 03/85 Others (7) - 09/85	**Files Porto** (42/304): 0.22 x 0.08 m – 32/42 0.20 x 0.10 m – 04/42 Others (6) - 08/42
King post (KP)	**Files Porto** (30/130): 0.22 x 0.08 m – 10/30 0.20 x 0.08 m – 08/30 0.18 x 0.08 m – 04/30 Others (7) - 08/30	**Files Porto** (17/304): 0.22 x 0.08 m – 11/17 Others (6) - 06/17
Ridge beam (RB)	**Files Porto** (16/130): 0.18 x 0.08 m – 04/16 Others (9) - 12/16	**Files Porto** (14/304): 0.22 x 0.08 m – 10/14 Others (4) - 04/14
Upper struts (S)	**Files Porto** (28/130): 0.20 x 0.08 m – 05/28 0.18 x 0.08 m – 05/28 0.18 x 0.08 m – 04/28 Others (10) - 14/28	**Files Porto** (13/304): 0.22 x 0.08 m – 03/13 0.18 x 0.08 m – 03/13 Others (6) - 07/13
-Timber wall plate (TWP)	**Files Porto** (13/130): 0.15 x 0.10 m – 03/13 0.11 x 0.08 m – 03/13 Others (6) - 07/13	**Files Porto** (07/304): 0.11 x 0.08 m – 02/07 Others (5) - 05/07

Table 3.6 – Synthesis of timber structures of the roofs characteristics [credits Alice Tavares]

	19th century (Porto)	**1900-1919 (Porto)**	**1920-1939 (Porto)**	**1920-1939 (Aveiro)**	**1940-1949 (Aveiro)**	**Regulations 1951/1956**
Second rafter (meters)	0.08 x 0.05 – 15/51 0.08 x 0.06 – 10/51 0.07 x 0.06 – 7/51 0.07 x 0.05 – 7/51 Others	0.08 x 0.06 – 19/48 0.07 x 0.05 – 4/48 Others	0.08 x 0.06 – 4/10 Others	0.11 x 0.07 m 0.12 x 0.08 m 0.08 x 0.07 m	0.10 x 0.07 m 0.07 x 0.07 m 0.7 x 0.5 m 0.08 x 0.07 m	Marseille tiles: 0.10 x 0.05 m *Canudo* tiles: 0.14 x 0.07 m
Spacing	o.35 m – 9/18 0.40 m – 7/18 Others	o.35 m – 9/21 0.30 m – 6/21 0.40 m – 5/21 0.50 m – 1/21	0.30-0.40 m	0.40 m	0.30 m	Marseille tiles: 0.5 m *Canudo* tiles: 0.4 m
Slats	0.03 x 0.02 m – 9/11 Others	0.04 x 0.02 m Others	0.04 x 0.02 m Others			0.03 x 0.025 m

Table 3.7 – Synthesis of second rafters, spacing and slats characteristics [credits Alice Tavares]

3.6.3. Typical amendments and strengthening features of roof trusses

The proper functioning of the amendments of elements is fundamental for the structure's stability and, thus, was also addressed in this study. The amendments between two elements to solve the need of a longer member or continuities are usually observed in horizontal elements such as roof purlins (Figure 3-55), ridge beams and timber wall plates with lap dovetail joints or scarf joints. This joint is commonly placed at points with low bending stresses, for example, as a brace support or above the principal rafters or even the ridge beam in the upper part of the king-post (Figure 3-56). This has the objective of restricting any disassembling of the frame due to torsion or to effects of variations in the moisture content of the joint and assuring that both pieces have a support surface. The shear load expected in the joint can be reinforced through the help of the design of a bridle scarf or halved scarf type of joint. The use of lap dovetails with nails or bolts is currently adopted.

Figure 3-55 – Amendement of purlins [credits Alice Tavares]

Figure 3-56 – Amendement of the ridge beam at the top of the king-post [credits Alice Tavares]

In relation to the strengthening features of the roof structures, a widely used solution was strengthening the alignment of the apex through a set of struts that were placed along the alignment of the ridge beam. The struts connect the upper part of the short king-post to a joist placed in the middle roof span and above interior loadbearing walls. This type of solution was often used in both regions until the 1920s and usually divided the distance of the supports of the ridge beam in two or three parts and independently of the truss typology.

Joints that connect members through notches were more frequently used in timber roof structures that were present in the period before the industrial revolution (prior to the 19th century). The consequent decline of woodworking was mostly observed in the 20th century to accomplish industrial methods (improvements in production scale, standardized shapes, faster execution, etc.). These led to the simplification of the joints and a progressive increase in the use of metal devices to guarantee the same functionality with fewer means and faster execution. As a consequence, less carpentry work was promoted, and metal elements (such as industrial nails) became essential to ensuring the correct contact between members.

The existent timber roof structures belonging to the survey show past repairs, such as additions or replacements (Figure 3-57), which result in the heterogeneity observed in the old structures. This is observed through the range of connections, the introduction of new elements, usually uprights, struts, collar ties or metal elements, with different timber species and consequently different mechanical characteristics. An example is the insertion of new diagonal scissor chords with the objective to go into tension and counteract the spreading of the trusses (Figure 3-58). In this sense, this repair intervention attempts to diminish the overstressed movements of some members, in addition to posts in the connection, helping to restrict the deformation of the purlins.

Thus, a complete survey contributes to understanding the history of the structure and to distinguishing the original structure from the subsequent changes. This can help to assess the type of 'solved' or 'unsolved' vulnerabilities across the lifetime of the structure. The recognition of failures of structures due to progressive malfunctioning of the connections is important for identifying the causes and effects on the hierarchical organization of the structure. This is a relevant step for conservation strategy.

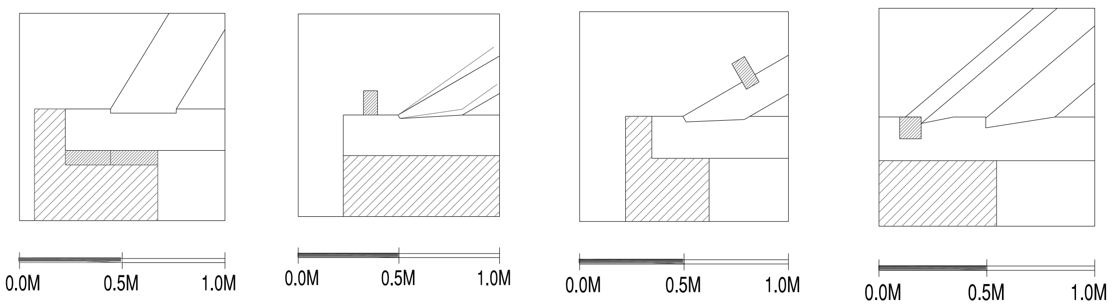
Figure 3-57 – Addiction of an upright to help in the support of deformed rafter [credits Alice Tavares]

Figure 3-58 – Addiction of new long struts connecting roof purlins at different levels [credits Alice Tavares]

In current practice, interventions that upgrade carpentry joints are mainly based on empirical knowledge according to tradition and are not specifically conceived for seismic actions, which often result in over strengthening (Parisi M. & Piazza M. 2008).

Again, the knowledge about the different solutions is relevant to the performance of proper retrofit actions with serviceability requirements. In addition, issues such as the timber elements subjection to environmental conditions, mainly due to their location near the supports (which can decrease their durability), should be valued in the assessment. The rafter-to-tie beam connection is usually considered the most important node of a truss, as observed when consulting traditional design manuals (Parisi M. &Piazza M. 2008) or due to the high level of stresses concentrated there but also because they represent zones where biological deterioration is more frequent. The experimental campaign carried out by some authors (Palma P. et al 2010; Branco J 2008; Thoma 2007; Parisi & Piazza) intended to contribute to the characterization of the mechanical behaviour of the rafter-to-tie beam connection, with or without metal devices, and the appointment of some effects of variations in the timber moisture content.

The data from the *in situ* survey in the Aveiro region reveal a large number of joints in their original configuration with no metal devices except nails. The joints show less complexity, and lap dovetailed shapes were used. Additionally, nails were generally used to avoid disassembly and to maintain loads transmission through proper surface contact by compression and friction. Another common joint assessed in the roof timber structures is the birdsmouth joint with a single tooth. The typical birdsmouth joints, even without any strengthening device, usually have a significant moment-resisting capacity (Branco J et al. 2009). The data from the in situ surveys are summarized in Figure 3-59 – samples A, B, C and D, which show variations mainly in the skew angle, in the joint location in the truss, and in the notch depth and length of the toe.



A - Connection present in high roof structures with more than 40º of slope

B - Slip mechanism in samples with low skew angle and less indentation of the joint

C - Identation of roof purlin in the rafter stiffening the roof structure near the supporting points

D - Joint with bigger notch depth and with a timber wall plate indented in the tie beam

Figure 3-59 – Examples of connections rafter-to-tie beam of the survey [credits Alice Tavares]

Comparing the problems observed *in situ* and the results of tests on full-scale connections that some authors (Palma 2010; Branco J et al. 2006a; Thoma H. et al. 2007; Parisi M. Piazza M. 2000, 2002, 2008) carried out to unstrengthen specimens under monotonic and cyclic loading or through numerical analysis, the following aspects can be highlighted:

- The behaviour showed by the typical birdsmouth joint (the most common type in the survey) skew angle of 30º was perfectly elastic until the elastic limit displacement (approximately 8 mm). A pseudo-plastic phase is present between 10 mm and 50 mm of displacement. After 25 mm displacement, a decrease in resistance is observed (Branco J et al. 2009).

- The brittle behaviour detected in examples with a decreased skew angle as the correspondent to the solution B was observed. A slip of the joint in the *in situ* case was observed. Nevertheless, the test specimens with similar characteristics presented a perfectly elastic behaviour only at the maximum force. In addition, after this, a slip action induced loss of friction and a rapid decrease in the resistance. The development of a shear failure in front of the joint itself is the result of loss of friction and compression damages. *In situ*, it should be noted that the effect of the wind on the structure and eccentric loads or joint defect in the tie beam are possible causes of the same effect.

- Rotational stiffness values are approximately half at 60º compared to 30º, all other conditions being equal (Parisi M. & Piazza M. 2008). This is a relevant aspect for solutions with type A present in the survey due to the vulnerabilities detected in the trusses similar to those in Figure 3-60.

- The notch depth has an influence on the resistant capacity (Branco J 2008), which can be observed in solutions of type D, where despite some other problems such as variations in the stiffness of the elements, which could impose some torsion to the elements, the rafter-to-tie beam connection does not seem to be affected. The deeper notch geometry also led to an increased strength (Palma P. et al 2010).

- Connections that were untied or damaged, particularly rafter-tie beam connections and those near the support are the main reason for significant decreases in the safety level of traditional trusses (Branco J 2008). *In situ,* we observed a horizontal crack of the tie beam immediately after the notch of the rafter. This is the result of stresses imposed by the rafter in the decayed end of the tie beam. As explained by Tampone (2007) based on similar situations, a failure of the joint between the rafter and tie beam (chord) occurs when the horizontal component of the compressive conveyed by the rafter along its axis, which is considered longitudinal but applied to the margin of the member and therefore a tangential compression, overcomes the strength the material (Tampone G. 2007) Figure 3-61.

- The presence of mortise and tenon, when adequately executed, can improve the joint's response (as for 12 or 20% moisture content), as noted by Palma (2010). The disconnection of the joints can lead to the rotation of the rafter and introduce instability to the truss.

Figure 3-60 – Displacement of the rafter in the connection to the chord or tie beam [credits Alice Tavares]

Figure 3-61 – Decay of the connection rafter/ chord or tie beam [credits Alice Tavares]

The failures found in the in situ survey were mainly disconnections such as loosening of the joints, breaking of the ends of the members, sliding of the top of the rafter, localized crushing of the joints (which can lead to further deformations, breaks or rotation) and cracks in the end of tie beams or near the connection with the rafter. As Palma noted, a good match between the surfaces in the notch and the consequent decrease of stiffness and strength values of poorly assembled joints is important (Palma P. et al. 2010).

All of these aspects need to be analysed in *in situ* surveys; however, direct assumptions cannot be made, as many variations can be found between the test specimens and the *in situ* solutions: timber species, cross section of the elements, distance from the end of the tie-beam to bear the top-chord, the skew angle, the depth of the notch, the height of the rafter (considered by Parisi & Piazza as having a significant influence), the width of the rafter and the friction angle, and the design of the joint; all of these aspects influence the results. A summary of the typologies compared is presented in Table 3.8.

Data of rafter-tie beam connection	**OTHER AUTHORS**				
	Branco J.et al 2006, 2009	Parisi M. & Piazza M. 2004, 2008	Thoma H. 2007	Palma P. et al., 2010	Trusses of the **survey** (sample)
Cross section of the rafter	0.22 x 0.08 m^2	0.20 x 0.20 m^2 0.20 x 0.15 m^2	0.15 x 0.15 m^2	0.15 x 0.075 m^2 0.14 x 0.075 m^2	0.10 x 0.20 m2 0.22 x 0.08 m^2
Skew angle	30º	30º	30º	30º	26º-30º
Notch depth	0.045 m		0.040 m	0.045 m	0.02-0.045 m
Distance from the end of the beam	0.442 m	0.20 m	0.20 m	0.45 m	0.41m (diverse)
Timber specie	Maritime Pine *Pinus Pinaster Ait.*	Poplar, fir, spruce, chestnut (*Castanea Sativa Mill*)		Maritime Pine *Pinus Pinaster Ait.*	*Pinus Pinaster Ait.*

Table 3.8 – General data of the design of the samples used in laboratory tests [credits Alice Tavares]

Another issue of the analysis was the use of metal devices in the roof trusses.

The aim of metal reinforcement was to protect the connection towards exceptional actions rather than to modify its normal mode of behaviour in elastic conditions (Parisi M. & Piazza M. 2008). The metal devices are not used to transmit forces directly; rather, they are to ensure the positioning and the proper functionality of the joint in eventual adverse or unpredictable conditions (Branco J et al. 2009). Therefore, they are important for ensuring the restraint of out-of-plumb movements of the elements, maintaining the adequate contact between connected elements. In this way, they maintain the surface contact throughout time even with some degradation, affecting the stability of the connection. Nevertheless, the shrinkage of the timber can restrict or enable this purpose and changes the shape and position of the assemblage of pieces (Parisi 2004, 2008). Moreover, the tendency to adopt standardized shapes and engage in less woodworking led to the reduction of ancient solutions and to the development of mass production techniques for nails and bolts (Ross P. et al 2007) to accomplish the demand. This increased the use of metal devices in less complex joint design, resulting in a cost reduction, as observed in the in situ surveys.

The truss with members that simply lapped and then bolted or nailed together tended to be completely reliant on metal connectors to strengthen and maintain the joint as equally strong in tension or compression (Ross P. et al. 2007). These elements were intended to counteract out-of-plane actions, which could not be avoided by the assemblage itself (Branco J et al. 2009). However, Parisi stated that only a moderate increase in rotational stiffness occurs in reinforced joints (Parisi M. et al. 2008).

Branco emphasized the greater resistance and the significant improvement in ductility (Branco J 2008). Considering this, Parisi alleged that in the seismic upgrading of the joints, in line with their original conception, metal connectors have to be renewed or applied to ensure the functioning of the connection in the case of the reduced compression that may occur during an earthquake (Parisi M. & Piazza M. 2004). Nevertheless, the upgrading or strengthening of traditional carpentry joints with metal connectors was mainly based on empirical knowledge, as emphasized by Parisi (2008), rather than seismic retrofit conception. For this reason, Thoma noted the importance of understanding the failure behaviour of full dimension joints. Particularly to optimize on-site examination and diagnosis of timber structures, the visual assessment and evaluation of strength properties of timber elements and joints can be conducted, which can be performed with greater reliability, with the objective of saving old timber members from replacement or heavy strengthening, if not strictly necessary (Thoma H et al. 2007).

The use of metal devices is mostly adopted in king-post trusses (KP), for longer spans and often for more than 5.0 m span.

Several types of metal connectors are usually present in the timber roof structures, mainly in the specific areas mentioned below:

- Nails – extensive to all connections;
- Bolts, clamps, binding strips – connection of rafter/tie beam and post/tie beam;
- Stirrup - connection of rafter/tie beam or post/tie beam or tie beam/wall plate;
- Rod – connection of king-post/tie beam.

The in situ survey of the buildings allowed us to record the changes in the structure due to the use of metal devices to achieve certain goals, which are dividing into the following categories:

- use of iron braces in the purlins and near its insertion on the walls. There are two objective of strengthening this area: the inclusion of other purlin elements close to the older element, to increase the load capacity of the structure with the two pieces acting as a single unit; and the connection of prosthesis to the old piece.

- use of iron strips to connect the king-post to the tie beam. The purpose of this method is to help mid-span support of and guarantee the stability of the structure. This is frequently used because the tie beam is the longer timber element and can, thus, tend to some deflection at the midpoint. In some solutions, the king-post is connected to the chord by joint and iron strips, rearranging the entire structural function, due to this rigid connection, which can be a problem and in situ was observed a rotation of the truss. Ortega stated that in some cases, the use of rods or binding strips connecting the king-post to the tie beam can also have a preventive function, predicting the later deflection of the timber members and the following re-engagement of the rod and re-transfer of the load to it. We also observed the use of iron strips to connect the end of the tie beam to the exterior wall.

- insertion of tie rods connecting opposite walls as an addition to ensure the impediment of the overturning of the walls or of movements of the roof structure. Tie beams are joined to wall plates through lapped dovetail or, in some cases, simple cogged joints. Nevertheless, the most commonly observed situation was the joint with a nail or bolt.

- other solutions also involve the use of metal strapping or stitch bolts to fix the principal rafters to the tie beam and to the head of the king-post.

- use of iron binding strips around the joint rafter/chord to prevent the rafter from sliding outwards due to the subjection of the loads in that area.

- ridge beam – use of iron plates connecting the lower part of the ridge beam to the wall as an anchor.

Specific effects involving the characteristics of each metal device can be noted from the laboratory tests carried out by some authors:

- Single bolt – behave initially as an unreinforced connection and is improved in the post-elastic range, reaching an appreciable ductility level and good capacity of dissipation. When the phenomenon becomes greatly extended, the reinforced connection continues to maintain contact, even if with large displacements. Failure generally occurs due to local fracture in the node (Parisi M. & Piazza M. 2004).

- Clamps – embracing the rafter and the tie in the notched area is also quite common, and although clamps can materialize in many different ways, their function is essentially to restrain the relative displacements between the rafter and the tie by compressing a certain area of the outer surfaces of both members (Palma P. et al. 2010). The clamped joints display brittle failure modes in the 12% moisture content joints and a reduction in strength when opening the skew angle with brittle failure in tension perpendicular to the grain in the 20% moisture content joints (Palma et al. 2010).

- Binding strips – the version adopted in the tests was a modern form that allows retightening. The strip is positioned in a notch in the timber elements. Despite the first loading, the sample showed an extension of the elastic phase and no fragile modes, the following stage showed brittle failure by sliding of the beam toe at the base of the notch, particularly for low skew angles (Parisi M. & Piazza M. 2008). The metal binding strips are present in several solutions of the survey.

- Stirrups – increased greatly the joint's strength. A perfect match between the notched surfaces is crucial; otherwise, there will be losses of strength and stiffness in the joints. The application of the stirrups after compressing the rafter led to an increase in strength and stiffness when compared to the joints assembled before the rafter's loading (Palma P. et al. 2010). The increase in moisture content from 12% to 20% was beneficial due to a tightened fit of the notch surfaces (Palma P. et al. 2010). The strengthening with metal stirrups reduced the deformation of the trusses by increasing the axial stiffness of the rafter-tie beam connections. Parisi recognized that the elastic phase extends significantly in this case. However, he stated that this device does not allow sliding between contact surfaces. It is not very deformable; thus, the energy dissipation is low (Parisi M. & Piazza M. 2004).

Furthemore, Branco (Branco J et al. 2009) noted the average values of dissipated energy on the original and strengthening joints under cyclic tests and showed its increase in strengthening solutions: i) Unstrengthened – 230 kj to 380 Kj; ii) Bolt – 1877 Kj; iii) Binding strip – 2874 Kj; iv) Stirrup – 1859 Kj.

In terms of the comparison of the strengthening techniques evaluated, the least efficient technique in terms of maximum resistance is the internal bolt, while the elastic stiffness of this technique is similar to that of the other techniques (Branco J et al. 2009).

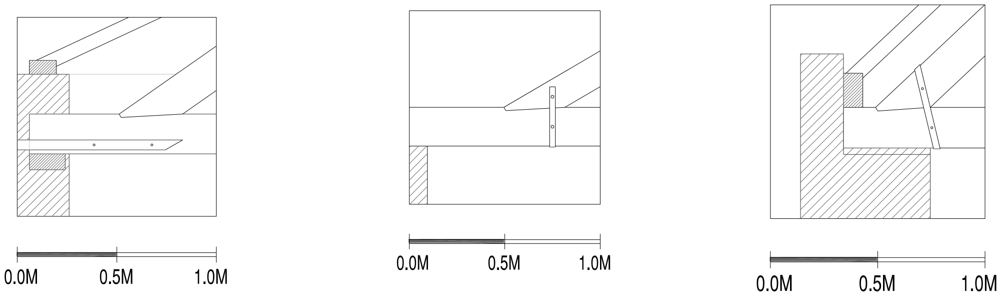
Connections that were strengthened with stirrups and binding strips attained the same range of maximum force, however, this last scheme has a lower ductility capacity and limitations in terms of maximum displacement (Branco J et al. 2009). Therefore, between the internal bolt and the binding strip, the former is more efficient in terms of ductility capacity with the goal to assure a better seismic behaviour of the birdsmouth joints typically presented in traditional timber roofs (Branco J et al. 2009).

The metal devices presented in the solutions of the survey (Table 3.9) are mainly iron clamps or stirrups that connect elements of the truss (Figure 3-62, Figure 3-63, Figure 3-64, Figure 3-65), as follows: i) the king-post to the tie beam - the most commonly used, even in earlier periods; ii) the principal rafter to the tie beam; iii) the king-post to principal rafters (the use of metal devices involving the rafters represents generically half of the solutions in the database; nevertheless, the two situations were not present simultaneously in all solutions); iv) the rafters to the struts - (less commonly used and associated more with solutions with metal devices in almost all joints of the truss); and v) the tie beam to the wall (several times observed in the *in situ* surveys; it is not mentioned in the written files of archives consulted). Concerning solution ii), solutions b) and c) represent two slightly different situations: solution b) was used to guarantee the expected position of the elements, and solution c) was used to maintain the position and to strengthen the joint by embracing the two elements and preventing earlier sliding of the principal rafter.

	CONNECTION OF TRUSS ELEMENTS THROUGH METAL DEVICES			
	King post **Tie beam**	**Principal rafters** **Tie beam**	**King Post** **Principal rafters**	**Principal Rafters** **Truss struts**
Number of trusses with metal devices (195)	149/195	98/195	98/195	18/195

Table 3.9 – Number of solutions with specific metal devices [credits Alice Tavares]

Figure 3-62 – Examples of connections of the king-post to the tie beam with iron strips and stirrup [credits Alice Tavares]



Horizontal stirrup | Vertical binding strip | Diagonal binding strip

Figure 3-63 – Metal devices recorded at in situ survey [credits Alice Tavares]

Figure 3-64 – Iron strip in all the joints of the principal elements of the truss [credits Alice Tavares]

Figure 3-65 – Iron strap connecting the tie beam to the wall masonry [credits Alice Tavares]

These solutions can be present in retrofit to withstand seismic loads; however, they require further updating, a more accurate design, and positioning and dimensioning of metal devices.

3.7. Conclusions

This chapter present an original approach to the evolution of traditional construction, emphasizing the adobe construction in the region of Aveiro. To achieve a wider understanding, data from the Porto region, a major influence on the Aveiro district, were used. Furthermore, resume tables were prepared that can help to characterise the adobe construction system and its evolution and adaptation to new materials and architectural conceptions. These can be used to prepare buildings assessments, and for this reason, the subchapter divides the construction system into its main components. A deep characterization of the timber structures used in floors and roofs includes research about the provenance of the timber. The roof structures of adobe built heritage present several solutions, some in disuse during the schedule program of this study. The connections and amendments in the timber elements of the structures were also addressed by this research.

4. DECAY, DEFECTS, INCORRECT INTERVENTIONS AND SEISMIC EVENT

4.1. Introduction

The main objective of this research was to assess the main defects detected in adobe construction as well as the causes for its disappearance in Aveiro district. Also, the arguments technician underlying the demolition requests of this heritage were analysed, including the identification of difficulties associated with its protection. To gather this kind of information, the archive files of municipalities used for previous approval of the architectural design were consulted. In addition, *in situ* surveys at Aveiro district were carried out to evaluate the reliability of the collected information (oral and written) and of demolition statements.

Moreover, the in situ surveys of defects/anomalies of buildings enabled the production of a database that could support future rehabilitation actions, and to analyse the adequacy of the implemented construction solutions in terms of durability. Understanding the reasons behind each defect can lead to proactive preservation actions that would be relevant to maintain this heritage. As pointed out by Silveira, the preservation of these constructions may also contribute to recognition of the advantages of adobe as a structural material, encouraging its use in new construction (Silveira et al. 2007). Furthermore, this could allow for a reduction in the efforts and resources typically associated with the demands for new buildings, replacing existing adobe ones (Silveira D et al. 2007). Advantages can also be applied for conservation actions.

There are several ongoing research studies at Portuguese universities, which are at different stages. Particularly, University of Aveiro has been developing work focused on adobe construction, for example, with respect to seismic resilience, thermal behaviour and mortar and adobe walls characteristics, to evaluate the level of vulnerability of this type of construction and more effective ways to solve the problems. Understanding the structural behaviour of these constructions will enable prevention of the structure's collapse under stress, and allow for an adequate rehabilitation, thereby increasing resilience capacity (Varum H et al. 2006).

Discussion of the increasing interest in many other countries (such as Peru, Brazil, New Zealand, France, Spain, Italy, USA and Australia) in adobe construction provides the opportunity to compare results/solutions, especially if standardised analysis parameters are concerted as pointed out by researchers in conference debates. This will enable better support for heritage protection.

Often these defects arise from a lack of maintenance, owing to the adoption of incorrect rehabilitation processes or both. This is due to an incomplete understanding of the construction system and lack of materials' compatibility assurance.

It is important to emphasise the differences between the potential vulnerabilities of the structures – the damages that occur mostly due to lack of maintenance and failed repairs – from the consequent decay of the structures.

The preconceived and outdated ideas of some technicians as regards this type of construction resulted in neglect of its high value in terms of environmental sustainability and cultural legacy. This is reflected in the reasons presented in their demolition proposals. The most frequently cited are the following:

1. The supposed high level of decay without possibility of restoration;
2. The need for "modern" living standards and "urban rehabilitation";
3. The need for greater space.

Finally, the study considers the kind of damages inflicted by the very strong earthquake and tsunami of 1755, which despite the distance of its epicentre from Aveiro district, affected this adobe region (Aveiro is more than 200 km from Lisbon). Such discussion provides additional background about the analysed defects.

4.2. Lack of maintenance and protection measures

Measures to protect this heritage should follow municipal or national guidelines. However, in most cases specific guidelines were not implemented, mainly concerning preservation actions that could stop abandonment (with consequent decay) or vandalism. In such cases, there were calls for police intervention, or application of new taxes or penalties, but clearly this was very far from solving the problem. The existing preservation measures are more associated with classified buildings or locals, or just the main facades. This is not sufficient, particularly in regions with adobe construction.

It should also be considered the migration effect to other central regions of Portugal (mainly, Lisbon and Porto metropolitan areas) or other countries such as the USA, Brazil, France and Germany. This was one of the reasons for the buildings' abandonment, as the owners or their predecessors did not return to the country. Secondly, the ancient buildings do not receive any maintenance care which leads to disuse. Thirdly, a very relevant problem concerns quarrels between heirs which lead to officially it is heritage of all heirs and in fact for maintenance or repair expenses it is assumed as heritage of anyone. The most common effects of abandonment or long periods of disuse are:

- Occupation by homeless people leading to significant destruction of all the building's interior mostly due to the use of construction timber elements in bonfires or fireplaces for heat during winter and other activities (there are six months when it is considered necessary to heat houses in the region). Fire events are common in buildings with this type of occupation leading to the total destruction of some buildings. In some cases, the owners tacitly approved of this situation, particularly when there were impediments to the building's demolition and they wanted to build a new construction with higher density and economical return;

- Theft of construction materials, such as ceramic tiles (*azulejos*), copper wires, doors and windows, decoration elements, timber elements (slabs or beams) and stone fireplaces. This was not restricted to interior materials, but also included parts from the main facade. The theft of ceramic tiles or copper wires has been recently the most damaging and involves parallel markets – legal street markets and illegal markets involving intermediate people. Both situations should be carefully analysed by authorities with timely prevention measures. These increase the cost of future rehabilitation actions and loss of the original elements of the building as well as graffiti damage.

The lack of maintenance was noted mainly in (Tavares A et al. 2014a):

- Roofs, namely, tiles broken or dislodged, downspouts and guttering, border elements near gable walls, chimneys, mansards or other roof volumes. Basically, no regular maintenance was implemented to check the conservation state of these elements, their correct position or need for repair. The lack of roof maintenance is one of the most common causes of building damage involving rainwater infiltration. Again, this is frequently allowed by owners to increase decay that can lead to a demolition order by the municipality. Considering this, regular inspection of the covering/roof is a very important action since loose/raised tiles and damaged water inlets can create damage to various elements, such as wooden structures, ceiling plaster and deterioration of the wall paint coatings and mortar. At its initial stage, the cause is easily corrected. However, the lack of timely action leads to expensive repair works, as several different aspects are affected involving many professionals and working hours, not to mention the great inconvenience to the users who cannot utilise the space;

- Lack of rainwater drainage maintenance in the canals around the building perimeter, which increases the humidity of the soil but mostly, can change the charge capacity of the soil foundation or the area of compression. A rainwater drainage system without annual maintenance, or repair in case of defect, is a common source of damage in these buildings. The absence of drain pipes leads to the continuous fall of water onto the curtain wall/facade, creating excessive moisture in this area, enabling infiltration into the inner layer of mortar, size variations and the action of hitting the mortar aggregates, helps their detachment in areas often already subject to cracking. Other damage observed is the appearance of fungi, lichens or even plants (Tavares A et al. 2012a);

- Absence of painted walls and openings, or even the timber elements of the covering. Weather effects associated with the lack of maintenance produce degradation in successive mortar layers. If the water effects are continuous, this can cause damage to covering layers, as well as the adobe through the loss of the protection layer, leading to the disaggregation of its constituent parts;

- Absence of repair of the openings – functioning, substitution or reposition of glasses and bitumen;

- Absence of repair of the reinforced concrete elements or its layer of protection;

- Absence of punctual repairs of plasterwork or stucco;

- Absence of vegetation or mosses removal which normally introduces nitrates in the construction materials involved in their progressive decay.

4.3. Structural defects of adobe constructions

The structural defects are nowadays the most cited to justify demolitions of earthen constructions, and for this reason they need to be studied and evaluated for correct assessment and demystification of the problem. For the analyses of structural defects the subject is divided into the main components of the construction, following the structure of the previous chapter – foundations, walls (exterior and interior), floors, roofs – including three other relevant issues – waterproof barriers/rising damp, thermal behaviour and seismic resilience. The cases identified as incorrect interventions are addressed and they reveal the gap between the research field and technical application or impact in public opinion. The incorrect repair or rehabilitation interventions are also main factors that introduce the idea of lack of value of old buildings.

4.3.1. Foundations

The problems concerning the foundations that can be assessed are the following:

- Foundation subsidence mainly occurs due to the collapse of the soil where foundations are buried (Figure 4-66, Figure 4-67). Since the soil is normally clay based, the foundation is easily damaged due to changes in small watercourses or subsidence on steeper ground. This produces negative effects on the structure, as foundations are often made of adobe and, despite their continuous form, they do not have enough capacity to minimise the effect of this problem (Tavares A et al. 2012a). Thus, as adobe walls are load bearing the effect is passed on to the whole construction.

Figure 4-66 - Photo of a building with subsidence damage to the exterior walls and roof [credits Alice Tavares]

Figure 4-67 - Detail photo of damage caused to walls due to foundation subsidence [credits Alice Tavares]

- Deterioration of adobe blocks or mortar disaggregation of the upper part of the foundations due to the effect of salts from the soil or from the effects of damage or nonexistence of water drain channels around the perimeter of the building which increases the level of soil humidity.

- Diminishing of the soil foundation confinement or changes in its layers which alter its load capacity, mainly due to new construction works on the periphery of the adobe building, whether they are buildings with basements or infrastructure with changes on the underground level.

- Out of plumb of interior foundations walls. This is observed in the upper part of the foundations walls, when changes are made to the interior of the building walls. These foundations are not continuous as usual; in some cases the base of the soil is not properly prepared and not levelled, which with time and progressive deterioration of the earthen mortar would change the plumb of the upper part of the foundations.

4.3.2. Walls and openings

In the first research stage the Art Nouveau buildings of the region were assessed because they represent the introduction of novelties in adobe architecture. Although these buildings have different levels of change, the most representative is associated with the main facade through the asymmetric volumes or facade design. Observing the other buildings built during the Art Nouveau period in Ílhavo, a number of characteristics can be read as novel introductions relating specifically to that influence, while others continued to be more rooted in the local tradition. The new design for the region and construction solutions had some positive and negative implications for the seismic behaviour of these buildings and for the durability of the solutions. Some of these concerns were identified:

- Some of the Art Nouveau buildings have long lateral facade walls (as 20.0 m), which can allow the out-of-plane mechanism when they are not properly connected to the transversal timber rod elements. The wall thickness reduction in height may also contribute to this mechanism. The traditional buildings typically have these long walls; however, they have mostly just one floor. The use of metal ties connecting opposite walls was observed in some cases and in others the structure of the roof accomplished the tie role. The use of two or three floors increased the possibility of this type of problem and required additional measures, sometimes two levels of tie elements;

- The new urban regulations adoption with their specific health concerns and requirements in terms of natural lighting in the Art Nouveau period induced more openings in the buildings. This could contribute to structural vulnerability of adobe buildings. The metric between closed parts and openings as addressed by Lourenço (Lourenço P et al 2006) show how these changes could affect negatively the building due to the greatly diminished spaces between openings, sometimes with just a thin stone member in between. In addition, the new architectural design concept introduced more irregularities in the openings, in terms of their shape and location in the facade wall. The adoption of larger openings can cause stress concentration in wall panels as well (Tavares A et al. 2012b). Nevertheless, after the time window of Art Nouveau traditional construction continued to use spaced windows.

- Some urban regulations imposed requirements in terms of minimum storey height. The purpose of this was to increase interior height in relation to vernacular architecture and increase the salubrious conditions of the interior. However, this could again lead to the lower resistance of adobe masonry to horizontal loads.

- Taller buildings with added salient volumes in the main facade, to distinguish the entrance, or adopting small towers, and a terrace in the back facade introduced in-plan irregularities. Despite the fact that these added volumes/elements could contribute to restrain the movement of the main facades in some situations, they may also induce torsion movements in the building and stress concentrations in parts of the construction.

- Heavy stone features were typically added to the Art Nouveau facades. Damage was reported during the seismic events of 1962 and 1969 in Lisbon (CML 2006), detailing how the ornamental elements on the front facade of an Art Nouveau building (located in Av. da

República) collapsed and its chimney. This caused damage to the roof and ceilings. The connection of the chimneys to the building structure and its location are a common structural problem in old buildings, and not only Art Nouveau buildings, due to the material decay and damages in the support base.

- The specific case study of Vila Cecílio – the end of Art Nouveau in Ílhavo (1919) – has an internal organisation more 'organic' similar to a house in Rua do Monte do Crasto (Foz do Douro) in Porto (Mota N 2010). The technical specifications used in Porto, where the solution involved a more concentrated plan, probably influenced the construction in Ílhavo. However, the irregular volumetry may cause uncontrolled tensions in a seismic event, as well as the abovementioned.

Concerning the general traditional adobe construction, the in situ surveys made possible the presentation of the following defects of the walls:

- Vertical cracks along the height of the wall. These cracks can be attributed to six different causes depending on the location of their occurrence:

a. Vertical cracks in the corner areas – this is a common damage in adobe walls and can be associated with differences in the thickness between the front facade wall and the gable wall (assumed also in the regional reconstruction regulations). This can lead to the different behaviour of the two walls, with the consequent vertical crack. However, there are other causes of this defect; one is less imbrication in the adobe rows or less rigidity in the corner and the other is the overturning of the front facade due to out of plane movements imposed by the structure of the roofs or the floors.

b. Vertical cracks in the transition area between two areas of the same wall. This can be due to slight change of direction between the two parts of the wall (to follow the curve of the street, for example) or age differences; that is, enlargement without guarantying the continuity of imbrication of adobe blocks along the rows.

c. Vertical cracks in long walls. This is usually present in long constructions where the gable walls are more than 7.0 metres long. The relation between the thickness of the exterior wall and its length without connected regular spaced transversal interior or pilasters will allow the occurrence of this defect, which is also commonly observed in simple walls of division of properties.

d. Vertical or radial cracks in the alignment of beams. This occurs when the load capacity of the wall is not sufficient in relation to what is imposed by the beam.

Generally, these cracks are not long, which is due to the introduction of horizontal loads by the changed action of the roof structure, making the upper connection of the walls difficult.

e. Vertical cracks in the area of transition between two volumes with different heights in the same construction. In some cases the reinforced concrete ring beam used was not sufficient to counteract this problem. Changes in the construction height/volume present the same degradation factor, since buildings are subjected to cracking resulting from distinctive mechanical behaviours between the two volumes.

f. Interior vertical cracks along the intersection between exterior walls and interior walls. This is a common defect in old adobe buildings, mostly when the interior walls are *tabique* walls without spaced connections (through timber or metal devices) with the exterior adobe wall. For this reason, there is a separation tendency of the two structures which in some cases is more visible, as in the cases of overturning of the exterior walls due to lack of tie elements, their deficient behaviour or even the incorrect position of the tie elements. The collapse of the walls due to this fact may also cause the collapse of the roof structure.

- Diagonal cracks due to the ground settling;

- Diagonal cracks near the openings angles due to timber lintel degradation, deficient functioning of the lintel arch or even inappropriate design of the lintel in its support area. Another factor is the lack of repair of cracks in exterior walls, which enables water ingress to construction elements. By changing their size configuration (expansion/retraction), this can create damage to coverings, causing detachment of mortar facings, which can be easily observed at openings (Figure 4-68 to Figure 4-71), specifically, at the wood wedge spots of door and window installations/frames;

- The corrosion of iron elements inserted into walls to fasten gates is another factor responsible for walls deterioration. The absence of corrective measures will in time affect a larger area of the wall (Tavares A et al. 2012a), as in the case of cracks that occur in the stressed areas of the angles of the openings;

Figure 4-68 - Damage caused to mortar at the wood fastener of the window [credits Alice Tavares]

Figure 4-69 - Detail of covering degradation at the window frame [credits Alice Tavares]

Figure 4-70 - Window degradation [credits Alice Tavares]

Figure 4-71 - Detail of window lintel degradation [credits Alice Tavares]

- Insufficient distance between the window lintels and the cornice/eaves. As this is almost the same area where the timber beams are embedded, it increases the fragility of this part of the wall which can decrease the durability of the eaves due to higher level of cracking;

- Mortar detachment associated with a high level of cracking can reveal serious structural problems in walls; its causes can be related to subsidence or loss of structural cohesion of the walls. Mortar detachment can also occur in situations where there is a lack of adhesion between mortar and the support, resulting from moisture ingress, due to the application of an excessive mortar thickness or even problems of compatibility with the support. The collapse of the covering layer will lead to the progressive disaggregation of the adobe blocks which sometimes takes 0.10 m from the thickness of the wall, in some cases without its collapse;

- Short eaves, not sufficient to protect the wall from the impact of rainwater. It should be noted that the higher exposure of the curtain wall/facade, due to the solution of progressive reduction at the eaves or even its absence and replacement by platbands until the 1950s, meant higher subjection of the walls to both water effects and loss of paint coating. For this reason changes were made to construction coverings, by adopting materials such as industrial ceramic tiles, quite often without any aesthetic quality. It can also be observed that the lack of both protective elements on the curtain wall/facade and regular paint coatings, favours, at first, the detachment of the covering in areas of water passage or permanence at the curtain wall/façade;

- Degradation is more frequent in specific areas of the curtain wall/facade, such as projections or associations of new and too thin elements without drip edges. Normally, this is associated with reinforced concrete (RC) design elements of the facades or stone elements;

- Efflorescence, with degradation of the painting due to the presence of salts with higher level of moisture in the base of the walls. This is a common pathology in buildings where the ventilation space of the basement is not properly guaranteed due to the use of floor screed or concrete ground bearing slabs in some areas of the construction. As a consequence, the ventilation in the base of the walls is decreased. In other cases, it is also due to the diminishing area of openings of ventilation, mainly to the street and backyard facade, when the exterior ground level rises above the level of these openings. In other cases, lack of awareness of how these openings function led to its closure by the owners;

- Presence of patches and mould on the walls due to lack of ventilation or water infiltration. Nevertheless, it shows a long-lasting high level of moisture in the wall. This is also observed when the stormwater downpipes are damaged or are missing.

4.3.3. Floors

The defects in the floor structure are frequently associated with the following problems:

- The lack of ventilation of the top of the joist embedded in the wall is a major difficulty and allows, in many cases, its degradation due to higher levels of moisture in that area. In addition, the degradation of the top of the timber joists causes a loss of stability in the floors and also in the connection between opposite walls, which has implications for the structural behaviour (Tavares A et al. 2013);

- Infiltration associated with entrances or near the balconies or terraces is usually the cause of increased moisture inside the walls, with the consequent degradation of the embedding areas of the timber joists;

- Deformability of the timber structure. Some of these cases are associated with overcharge of the load capacity of the timber joists, mostly when they do not have extra transversal connections such as billets (*tarugos*). This was also observed in the functional changes of the building spaces;

- Timber elements degradation due to xylophagus agents (insects or fungus), commonly the *hylotrupes bajulus*, *lyctus brunneus* and *serpula lacrimans*. Usually, the favourable moisture conditions for the fungus and other xylophages agents action is considered above 20 % of moisture content (Ross P et al. 2007). However it depends on the agent in question. The neglect in maintenance, combined with bio-deterioration or a load increase, could lead to very severe structural problems (Thoma et al. 2007). These can produce serious damage and decrease of the wood structure resilience. In Portugal, there are still great difficulties in implementing a national monitoring framework to evaluate the evolution of this phenomenon, assessing its damaging effects and finding eradication solutions. The exception is at Azores Island (SCIT 2010) where the problem of infestation of termites required a wider strategy, involving university-level research, in situ testing measures and rehabilitation guidelines for the builders, technicians and owners.

- Timber defects that can cause a decrease in the load capacity of the beams and consequently, affect the rest of the structure.

4.3.4. Roofs

Anomalous situations in roofs are avoidable with proper and periodical maintenance, correct assessment and repair. The roof structure defects identified in the in situ surveys and the comparison with what was prescribed at the time allow to be concluded that some of these defects are mostly associated with bad construction originally using early industrialised methods, as a result of increased demand for housing after 1940. The defects are normally associated with:

- Cracks in the principal timber elements of the roof structure. This was more observed in purlins, tie beams and the principal rafters of the trusses. Such common defects compromise the stability of the structure and can lead to its collapse. The first cause of this problem is usually unroofing near the truss elements, due to wind or human action, with the consequent rainwater infiltration and decay. Another reason can be the overcharge imposed on the element.

- Deformability of the principal elements of the roof structure (mainly purlins, tie beam or rafters). This is usually due to insufficient cross section of the elements, sometimes even in their original shape. The comparison between the construction regulations of the time and the in situ assessment confirms this conclusion, besides the deformability of the timber structural elements. The evolution of the construction system including the sequence of regulations (national or regional) shows a tendency to decrease the cross section of elements throughout time. The builders frequently adopted inferior cross sections in relation to the minimum prescribed in the regulations which were already near the limit of the load capacity expected. This was one of the causes of this type of problem in old adobe buildings after 1945.

- Crushes located at the support areas of the wood structure can also be observed (Tavares A et al. 2012a). The decay of this part of the timber elements is again due to lack of ventilation in the embedding area, lack of roof maintenance and damage to the roof covering. Such problems may be responsible for damage to the walls. The common decay of the ends of the tie beam truss due to its role in the stability of the structure is another problem, which affects the walls. The cause is usually due to excessive application of mortar above it, to fix the tiles near leading to water ingress.

- Cracks in the walls of the attic due to slight movement in roof trusses against the typically thinner walls of that area. This is usually observed in the type of trusses supported by short timber pillars or struts with connection to the walls (mainly Solution STS, see chapter 3). The load will exert more pressure against the walls, leading to cracks and movements incompatible with the cohesion of the adobe wall system, and resulting in great impact at the level of the corners. To counteract this eventual problem, it is observed tie metal rods embedded in the gable walls and connecting the principal facades to avoid out-of-plane movements imposed by the roof structure.

- Decrease of the rafters load capacity due to deformability as a result of inadequate dimensioning or spacing to withstand the loads, which can increase with ageing or decay of the timber members. Again, this was confirmed through the comparison of the construction regulations with the *in situ* assessment. The symptoms of deformation, the cracking or even broken rafters are observed from the exterior as a slope bowing or change of the position of tiles.

- Sometimes, it is also seen deficient amendment repair of two members that constitute purlins or ridge beams, which leads to deflection and separation of the two pieces of the element. The decreased complexity of the configuration of the amendment with reliance on nails, but insufficient use (number of nails), revealed with time some neglect in the method of construction. In addition, a lack of criteria for the correct position of these amendments in the structure which were sometimes located outside the elements support increased the possible defect.

- The demolition of interior *tabique* walls without proper evaluation of their secondary function as a structural element (which in some cases can occur) is another cause of deformation of roof trusses due to the decreased supporting area. This is a common misconception. Similarly, loadbearing interior walls are demolished in the floors below without proper evaluation of the impact at the roof structure level. The problem is particular evident in more complex roof structures.

- Infiltration due to roof elements loss, the deterioration of covering materials or lack of maintenance. This is mostly associated with particular volumetries of the roof with different materials, such as chimneys, garrets or the higher gable walls of the closest buildings. The low durability of the materials or the interaction/movements of these volumes lead to defects in the waterproofing in the transition areas of roofing (Tavares A et al. 2014b). Such a common problem affects even the floors below due to infiltration, if not promptly repaired. Infiltration is also observed when the eaves are damaged (sometimes due to heavy vehicles traffic), which allows faster degradation of the cornice area of the wall and in other cases reaches the embedding level of the timber beams. The narrow dimensions of the pavements or their absence are additional cause.

- Decay of the timber wall plate, an element that, besides its connection function between the roof structure and the wall, gives more load distribution uniformity from the roof into the walls and helps to counteract the out-of-plane movements of the walls (Figure 4-72, Figure 4-73). This problem is due to a lack of ventilation in the area of the attic or roof void, including excess of mortar involving the timber element, which increases the moisture around the timber piece.

- Xylophages agents. The moisture permanence at the covering/roof area is one of the potential causes for the appearance of wood xylophages. This problem is mostly associated with the lack of ventilation in the roof void, due often to ‘conservation’ measures blocking the possibility of ventilating the timber elements.

- It should also be considered the timber defects influence on the structural behaviour. In particular, knots, splits and drying shakes can reduce the timber mechanical strength, predisposing it to fracture (Tampone G 1996, 2001). Splits are separations of wood fibres that extend completely through the width or thickness of a wood member. Short splits typically do not affect the performance of a wood member, but the engineers should evaluate long splits if there are concerns about shear strength in beams or buckling in columns (Anthony RW et al. 2009). Another issue necessary to assess is the presence of cracks in the members. They are quite different according to the nature of internal tensions caused by compression or tension or bending, shear, or torsion, and also to the absence or presence of decay agents such as insects and fungi.

- Since the 1920s, the common introduction of platbands in the main curtain walls/facades led to some decay related to insufficient sizing of gutters or inappropriate waterproofing (Figure 4-75, Figure 4-76, Figure 4-77). Considering the platband configuration, durability problems appeared with permanent moisture at the top of walls, cross cracking incidental to an incorrect connection between platbands and the existing wall, as well as degradation of the wooden covering structure.

- Fire. It is not common that fire starts at the roof level. However, when it does occur the roof is highly affected due to the presence of combustible materials, although most of the time the façade walls remain standing. The structural capacity of the walls is not usually evaluated afterwards and the building is simply demolished. Research is necessary to assess the fire effects on the walls.

- The lack of guttering enables the flow of rainwater onto the curtain wall/facade. This rainwater flow can infiltrate through micro-cracks in the rendering, amplifying these cracks and enabling fine materials removal from inside the wall, thereby leading to mortar detachment. The lack of gutters is also responsible for the appearance of lichen and moss, which further contributes to mortar degradation (Figure 4-78).

Figure 4-72 - Photo of a building with corner degradation (Eça de Queiroz's family house, Verdemilho) [credits Alice Tavares]

Figure 4-73 - Detail photo of the degradation at the upper part of the corner [credits Alice Tavares]

Figure 4-74 - Detail photo of a crush located at covering level [credits Alice Tavares]

Figure 4-75 Damage to the rain water drainage system [credits Alice Tavares]

Figure 4-76 Damage to the wooden covering structure[credits Alice Tavares]

Figure 4-77 Damage to the plaster ceiling [credits Alice Tavares]

Figure 4-78 Moisture in the walls[credits Alice Tavares]

4.3.5. Decay of the reinforced concrete elements

The reinforced concrete introduction was gradual and with changes in the characteristics of the materials used. In the beginning, the so-called “cement ring beams” could only have a very low percentage of cement in the composition, as it was concluded in the laboratory analyses of this type of element in the case study of the Theatre of Ílhavo (probably of the 1920s). Gradually, the percentage of cement used was increased and the choice of calibrated aggregates was made more carefully. Nevertheless, it was observed that in a high number of existing buildings the reinforced concrete was damaged, namely, in all the elements with covering or just a very thin layer of coating or even without painting. These damages are more noticeable in protruding elements such as thin slabs in the front facades, ring beams close to the eaves level, balconies and others.

The most common defects are (Figure 4-79, Figure 4-80, Figure 4-81):

- Corrosion of rebar showing the absence of mortar cover. This situation is easily observed in thin elements of the curtain wall/facade, such as tile shades and balconies, but also in beams and decorative elements present in the curtain wall/facade.

- Lack of dripping pans in slabs, beams and other protruding elements, which allows long-lasting moisture permanence on the elements (Tavares A et al. 2011).

- Concrete degradation due to behavioural deficiencies, in particular, loss of load capacity, which if not corrected will cause cracking in the elements. These cracks will be responsible for water supply to the inner iron armour, causing its corrosion and aggravating the situation.

- Cracks or detachment of mortar around the reinforced concrete elements or cement based elements due to incompatibility between materials (cement X adobe or earthen mortar) and incompatibility between the mechanical behaviour of adobe walls and the reinforced concrete elements.

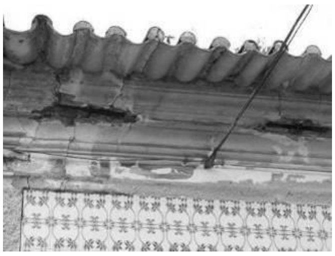


Figure 4-79 - Tie corrosion [credits Alice Tavares]

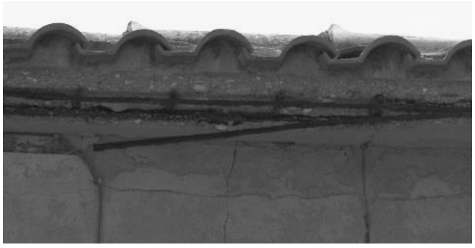


Figure 4-80 - Steel corrosion in reinforced concrete beams [credits Alice Tavares]

Figure 4-81 - Steel corrosion in the concrete of a balcony [credits Alice Tavares]

The most commonly reported problem in adobe constructions during this period is iron corrosion used in the reinforced concrete, mainly in the thin elements of the main facade, which is more subject to wear caused by vehicles, air pollution and moisture. It is often observed that the building has problems in the reinforced concrete elements but not with the rest of the adobe construction, which is still in good condition.

4.4. Non-structural defects and comfort

This research identified two other main problems involving non-structural defects that also contribute to the disappearance of this building heritage. The most common justification for significant but questionable changes in these buildings is that only new materials and techniques can achieve good interior comfort or durability. The information analyses regarding studies related to defects in new construction by other researchers (Freitas VP 2008; LNEC 2003) also revealed the high prevalence of defects.

Two main issues will be addressed, the rising damp and the thermal behaviour, to highlight the reasons behind loss of confidence in the adobe construction system features and to characterise both problems.

4.4.1. The rising damp and waterproof barrier

One of the factors responsible for damage in the adobe construction system is the known effect of water/moisture, and as such, the lack of care to both rainwater drainage and basement moisture.

In many buildings, assessed for Master degree courses at DECivil-UA, it was identified that the decrease in the height of the base of the ventilation space and the insufficient size of ventilation windows were the two most common causes. Furthermore, the reduction in the number of these openings for ventilation, their obstruction or the impediment the placing them in opposite walls to guarantee that all the space is ventilated, is an additional cause. Even the construction regulations mentioned the need for space in the base of the construction, but also revealed a decrease in its size in several publications.

Moreover, this problem of the insufficient size of the ventilation openings is also associated with an increased level of the footway or even obstruction of these voids by the owners. The successive increase of the footway level due to urban interventions through the application of layers above the existing ones, without any adjustment with regard to the base ventilation, is a problem mainly in urban settlements. In some other cases, this level increase of the footway exceeds the level of the interior ground floor of the construction, which introduces another problem. In this case, the waterproof barrier is kept below the contact of the rainwater that runs along the pavement. In some old regulations the waterproof barrier was only obliged to achieve the level of 0.20 m above the footway. Both examples are associated with the causes of the mentioned problems.

The wide use of the screed floors prevents the correct ventilation of the construction base, which is a major reason for walls decaying due to rising damp effects. The absence of a ventilation wall cavity at the wall base enables the formation of moisture in basements. Furthermore, the absence of materials that create a waterproof barrier between the foundations and walls increases this type of damage to the construction. This problem is amplified when the lack of good perimeter water drainage leads to high levels of moisture in the soil, thus increasing the rising damp and affecting with time the timber structure of the floors on the ground floor. In some buildings it was observed the use of an element to "sacrifice" immediately below the timber structure that is most impacted by rising damp. This can be a second piece of timber along the base of support walls, or a layer of bricks or even the ring beam of reinforced concrete. Besides the use of a reinforced concrete ring beam that some technicians mention as having a secondary role as a waterproof barrier, during the 1940s diatomaceous earth was used in addition to cement mortar or lime mortar to increase the supposed waterproof barrier capacity. Nevertheless, these reinforced concrete ring beams cannot assume that role, as their effective waterproof capacity is dependent exclusively on the addition of a waterproof material to the concrete (with a correct ratio). This creates an appropriate particle size curve of the aggregates and methods of construction that guarantee the compactness required, which was not observed. The use of tiles or bricks as a barrier was revealed to be insufficient to prevent the rising damp from reaching higher levels, which can easily be 1.0–1.2 m.

Another interfering factor in the wall quality concerns the location of old buildings. They are mostly located in old, narrow streets, with reduced pavement widths or even without any. Therefore, water and particle/particulate projections from the traffic are directed against the walls (Figure 4-82). Thus, either the pressure of the impact or the permanence of moisture in these areas leads to the degradation of the building stem wall. Moreover, the lack of both water ditches and a waterproof barrier between the foundations and wall also leads to dampness in basements. Furthermore, the use of paints which are incompatible with the supporting surface will in time lead to their detachment from the wall (Figure 4-83, Figure 4-84), since they do not allow the wall to develop the necessary mechanisms of moisture balance with the external surface (Tavares A et al. 2012a).

Figure 4-82 - Photo of the degradation of the building stem wall [credits Alice Tavares]

Figure 4-83 - Photo of the degradation of inside paint covering [credits Alice Tavares]

Figure 4-84 - Photo of the degradation of outside paint covering [credits Alice Tavares]

In some other cases the compliance with the national regulations of civil property protection, along with eaves failing to project rainwater to neighbouring land, as the buildings have very short distance between them, usually less than 0.50 m, resulted in several problems. Firstly, it was very difficult to clean these spaces, and the ventilation and repair actions were also difficult. Furthermore, the moisture level increases at the base of the walls. This problem was usually associated with a high level of salts leading to the decay of the adobe and mortar, which are in these cases often not covered by plaster.

4.4.2. Thermal behaviour of adobe buildings

The thermal behaviour of adobe buildings is one of the positive aspects mentioned by several researchers. In the last two years, the DECivil-UA developed an in situ thermal monitoring protocol. The preliminary results show that the comfort parameters envisaged in the Portuguese Regulation of Thermal Behaviour of the buildings (RCCTE 2006; DL 118/2013), Decree-law nº 80/2006 of 4 April and Decree-law nº 118/2013, are not fulfill by some of the adobe recent buildings with thinner walls. Characterisation of the thermal behaviour of the buildings under the RCCTE guidelines is made through the calculation of needs of energy consumption in heating and cooling seasons for m2 of useful area. It is highly relevant the balance between the comfort demands without excessive energy consumption and other negative effects such as condensations.

The monitoring of residential buildings was carried out at Ílhavo and Aveiro; the region is considered as zones with needs of 6.3 months of heating. This period of the year is related to high loss of energy, mostly through the roof due to lack of insulation materials in the traditional construction system where only ceramic tiles were applied as covering material. Other construction aspects do not help to counteract this problem such as thin glass (often just 3 mm thick) in the windows. On the other hand, several houses have interior timber shutters usually 5–10 cm from the window. These elements help the interior temperature maintenance, although they require regular use to diminish higher fluctuation of temperature. All these aspects need to be addressed in rehabilitation interventions. Even in the cases where the front facade has higher thickness (more than 0.50 m), the gable walls usually have less thickness and need a previous evaluation of the need for thermal correction. When the buildings are aligned, close to each other and of the same height, there is no such problem, but often this is not the case.

Natural ventilation is another issue connected to thermal behaviour, comfort promotion and durability of the materials. In the traditional adobe buildings this was naturally promoted through the interstitial spaces in the openings and in the roof. However, the new understanding of comfort and energy efficiency led to the conception of hermetic spaces where everything should be mechanically controlled. This is an aspect that when applied without any criticism leads to the progressive deterioration of the interior ambience and decay of materials in this type of construction. Moreover, as residents are unable to afford the energy consumption needs of the mechanical ventilation when applied, it is also switched off most of the time due to high functioning costs. This is also observed in new rehabilitation actions at schools with reports of fast decaying materials even in the guaranteed construction period. Although for these buildings the legislation is followed, clearly, there exists a gap between its objectives and the reality, and a reasonable balance should be evaluated by the technicians concerning probably the natural ventilation control. In addition, the substitution of the original timber frame of the windows and doors by aluminium frames diminished considerably the ventilation which, with the lack of effective mechanical ventilation due to unsustainable costs and noise, very soon resulted in less healthy interior environments.

4.5. Incorrect interventions – the introduction of new vulnerabilities

The need to retrofit the traditional adobe constructions – expectations of higher quality space – and to follow the new architectural design, introduced some other problems. The most observed defects in buildings, related to the changes introduced in traditional construction system, were:

- Progressive use of lower thickness for load bearing walls, threatening some pier anchorage/insertion areas;

- Demolition of basement walls to expand spaces triggering the collapse of the upper floor;

- Structural regularity loss due to changes in the facades or the demolition of interior walls. From the 1940s to 1950s alterations were frequently made to the interiors of residential buildings. The main objective was to broaden these spaces, in particular the connection between the living room and the dining room, and to remove the main hallway to improve lighting. Therefore, the structural performance was affected, since the distribution of loads was changed, overloading the remaining walls. The effect of this can be seen through the cracks that appeared in the walls and unevenness in the top floor;

- Demolition of parts of walls without ensuring the proper load capacity of the remaining part – cracking is the most usual effect or in other cases the collapse of the remaining structure. Other problems are associated with rehabilitation either for expansion or alteration. Without an adequate evaluation of the structural reinforcement, the demolition of loadbearing walls inside the houses leads to floor collapse and/or movements beyond the wall's plan (Tavares A et al. 2012a).

- Introduction of new reinforced concrete elements. In some cases the introduction of pillars embedded in the adobe walls in recent rehabilitation interventions can be a problem, due to the reduction of the section of the wall – for example, 0.25 m inside a 0.40 m thick wall – which in some cases led its collapse. The differences in structure rigidity (adobe walls and reinforced concrete elements) can also lead to cracks. The other main problem is the substitution of the timber structure of the roof by reinforced concrete slabs. This can lead to three different types of defects: cracks in the walls due to the overcharge imposed on the walls in their lower thickness section; overturning of the walls due to horizontal movements imposed mainly by pitched roofs; increasing of the moisture level inside the building, due to insufficient additional ventilation in such cases;

- Cutting of principal wooden structural parts of the roof trusses for casuistic expansion of the ceiling height or enlargement of the living space, transforming the void of the roof in an attic. This is mostly associated with interventions after 1950.

- Obstructing the access to the roof void in recent interventions. This prevents the possibility of promptly repairing any problem in the roof structure or in its covering. It is necessary, therefore, to build a temporary access outside of the building, for the annual maintenance inspection. For this reason, the inspection does not occur as often as it should, and then only when problems are detected on the lower floors. The old buildings had access to the void of the roof. As a result, solutions to problems often caused by the wind during winter could be more quickly found;

- Use of timber elements in repair actions without full understanding of the functioning of the entire structure. This is particularly observed in the roof when struts are applied without criteria concerning its location and proper dimension or when a timber element of the structure is substituted for another with a lower cross section. In these cases the structure became instable in a short period of time.

- Platbands placement, using a reduced gutter section, therefore, losing its waterproofing feature, and allowing infiltration into the wall. The discontinuation of the use of eaves and installed platbands and the introduction of terraces with sealing problems were responsible for leaks and deficiencies in the rainwater flow control. The recognition of this problem led to correction interventions in the past, reverting the use of the platbands to the original building shape with eaves;

- Incompatibility between materials and techniques used – reinforced concrete beams to connect both walls at the corner – or the use of cement mortar to repair the covering of the walls – the detachment of plaster. The chemical and mechanical incompatibility between the new and older materials in the damaged area will result in increased problems.

The incompatibility of materials resulting from the cement mortar introduction during the conservation processes is a frequently observed error. This happens when cement is used in mortar covering, since the compatibility with the support is not secured. In this case, the "repaired" layers are rapidly detached, often dragging parts of the support with them. In the beginning, the use of cement mortar was normally applied in brick walls. However, some years later, it was also applied to adobe walls, which caused damage in the medium term due to the incompatibility of these materials. The cement mortar reaches its maximum strength in a very short time. In comparison, mortars based on lime progressively increase their strength, without suffering a significant strength decrease with age (Mellace R et al. 2007). The greater ease of cement mortar use, instead of lime mortar led to the neglect of traditional techniques, which were fundamental to the use of adobe blocks (Tavares A et al. 2012c). Lime works have better plastic properties than cement; from the moment of application and throughout their lifetime they have a greater solid flexibility, capable of keeping pace with support variations (Contreras 2007). It can also be observed that cement mortars achieve their maximum resistence capacity in a short period of time, and progressively lose resilience shortly after their application compressions (Mellace R 2007). The same does not happen with lime-based mortars, which progressively gain resilience without any later reduction; there are mortars which are over one thousand years old with resistence high compressions (Mellace R et al. 2007). Again, the use of cement mortars is observed to "repair" the damages of disaggregation of the granitic stones or limestone. The owners prefer to hide the problem with cement mortar instead of consulting a specialist in stone pathologies. The effects of salts and pollution are the main causes of stone decay in this region near the sea coast. The detachment of the cement layer continues to occur as observed in the adobe walls.

- Again, the use of cement mortar, in this case, above the timber wall plate in direct contact with timber to cover interstitials voids. This also led to the decay of the timber. On the contrary, it is pointed out by Ross (Ross P et al. 2007) that the lime mortars used in the old solutions have the necessary porosity, which helps quick drying and adding to the strong alkaline that can be a natural fungicide and insecticide (Ross P et al. 2007). The same can be said in relation to the addition of diatomaceous earth.

- Apart from the use of Portland cement renderings (external or internal), another defect frequently observed in existing adobe constructions is related to the application of non-permeable wall paints. The impermeable characteristic of these external layers in walls is mostly responsible for reducing the capacity of expulsion of moisture outwards, thus changing the natural balance that can be achieved with traditional mortars and paints. The lack of understanding of this phenomenon was one of the reasons for the traditional technique being devalued, which is still noticeable in owners and builders today. The effect is detachment of the paint from the wall and, as a consequence, the lack of protection of the wall against atmospheric agents;

- Use of ceramic tiles or cement rendering to hide the effect of rising damp in the interior spaces of the building, instead of solving the problem, let that efflorescence rises to a higher level of the wall.

- Obstruction of the ventilation openings at the building base and of the ventilation holes at the roof level. The reason behind this decision is often associated with the detection of high fluctuations of the interior temperature or the risk of birds or insects being able to enter. Therefore, owners close the holes and introduce a new problem of higher moisture levels in that space. There are other solutions without stopping the ventilation of the timber structures, but that is not what usually happens. In addition, the use of screed floor or groundbearing concrete slab for ground floors blocks totally the ventilation of the construction base;

- More recently, the government incentives to retrofit the buildings in terms of thermal behaviour led to massive changes in the facades of the buildings, changing systematically the timber windows or doors, without any evaluation of the cultural value loss that this kind of intervention represents. Again, due to the same incentives, thermal isolation elements were introduced in the roofs. However, these interventions do not always guarantee the necessary ventilation of the timber elements and decrease in time their durability. On the other hand, old solutions of thermal insulation using sponge led to an increase of moisture in this element and of fungus which impacted the health of the residents.

- The common use of carpets and linoleums to cover the timber boards of the floors led usually to decay of the whole timber material below. This tends to increase the permanence of moisture and fungus in these covers materials and the action of xylophages agents. Both materials do not allow the ventilation of the timber elements.

- One of the aspects that devalue the image of the building or the street is associated with the introduction of urban infrastructure too close to buildings to preserve. This is still an open debate, with many locals agreeing that the most correct insertion of these elements is in the existing building or in its surroundings.

4.6. What can be learned from the ancient earthquake experiences?

This research began with the in situ evaluation of old adobe buildings with some strengthening features, found only in some regions, which raised the question of the motivation behind these solutions. Although they improve overall structural performance and some of them are not exclusive to adobe buildings, it was considered necessary to find answers to this knowledge gap. Three hypotheses were considered: the remains of traditional construction practices following the ancient earthquake of 1755; the influence of other regions; and the growing knowledge about the structural vulnerabilities of the system. The last two hypotheses have already been analysed in the research literature, but the first hypothesis had never been assessed for this region. Therefore, written sources on the effects of the major earthquake of 1755 were analysed, as this event devastated the capital of Portugal, Lisbon, and also affected the region of Aveiro (more than 200 km from Lisbon). The objective was to analyse the type of damages observed in this adobe region, and which areas were most affected that could explain any greater concern to improve the structural connections observed in the ancient construction. Namely, the use of timber elements, at the floor and roof level, solutions for the corners and the use of tie rods (not only connecting opposite walls but also anchoring the front façade to intermediate walls of the construction) are examples. These features were not present in all the adobe construction regions. A second objective was to reach some conclusions about the structural performance of adobe constructions (Aveiro district) subjected to an earthquake event.

This part of the research was based on the documents of the *Memórias Paroquiais* of 1756 produced to answer the request of the Marquis of Pombal (the prime-minister), and for those areas with no information in this document, a second collection of documents from the *Memórias Paroquiais* of 1758 (MP 1758) was taken into account.

The *Memórias Paroquiais* of 1756 is a survey consisting of 13 questions answered at the time mostly by the priests or other clergy members, about the effects of the earthquake in all the parishes of Portugal. The questions were:

1. At what time did the earthquake of 1st November begin, and how long did it last?
2. From which direction was the quake felt more strongly? From the North to the South or the other way around? Did it seem that more buildings collapsed in one direction than another?
3. How many buildings collapsed in each parish? Did this include any notable buildings and in what state of repair were they?
4. How many persons died and did this include any high ranking people?
5. What phenomena were observed in the sea, springs and rivers?
6. If the tide ebbed or flowed, how many hand spans more than usual did it rise; how many times was the extraordinary ebb and flow observed; and was the time noted for the water to lower and the time spent for it to rise again?
7. Were there any changes to the soil (liquefaction) and did any new springs appear?
8. What measures were implemented in each location by the clergy, military or ministers?
9. What further earthquakes were felt after the 1st of November, for how long and what damages did they cause?
10. Is there any knowledge/memory of other earthquake events in the past and the damages caused?
11. How many people live in each parish, and how many from each gender?
12. Was there any experience of supply shortages?
13. If there were long-lasting fires, what damages were caused?

The answers to these questions were analysed for 63 parishes, with data for 4 parishes taken from the 1758 survey.

Although this adobe region is far from the earthquake epicentre, from these archives it can be seen that the earthquake was strongly felt in some regions (Figure 4.20), but there were no deaths.

As the original purpose of the 1758 survey differed from the aims of our research, only the answer to question 26 was considered ("what kind of damages occurred during the 1755 earhquake?"), relating to the damages to buildings due to the 1755 earthquake.

The analysis was divided according to five topics, to better understand what happened in the region and the effects observed:

a. Direction of the earthquake movement (North-South or East-West)
b. Descriptions that can be associated with liquefaction
c. Alterations in the level of sea, rivers or springs
d. Areas where the earthquake was strongly felt and the type of ground movements
e. The type of damage observed in buildings and the areas with no damage.

This information was summarized in the first table for a better understanding of the event. The

Table 4.1 – Table of localities with damages from the 1755 earthquake - identifies the topics a), b) and c) and the areas with collapse of buildings.

SELECTION OF DATA TO CHARACTERISE PARTICULAR ISSUES ABOUT THE 1755 EARTHQUAKE IN AVEIRO DISTRICT

DIRECTION OF THE EARTHQUAKE	PROBABLE DESCRIPTION OF LIQUEFACTION	VERTICAL MOVEMENTS OF THE SOIL	CHANGES IN RIVERS and FOUNTAINS	STRONG DAMAGES IN BUILDINGS/COLLAPSES (CHURCHES AND HOUSES)
Vila Chã (V.Cambra) E/W			Macieira de Cambra UD	Ovar, São Cristóvão (chapels)
			Ossela (Caima r.) HWA	
Macinhata de Seixa (Oliv. de Azeméis) All directions			**Macinhata de Seixa** (Covo river) UD	**Macinhata da Seixa** (Silvares – chapel of St António)
	Lamas do Vouga (Vila Verde)		**Lamas do Vouga** HWA	
Castelões All directions		**Segadães**	**Segadães** HWA	
Cepelos All directions			Belazaima (Águeda) FR	Santa Maria da Feira
Codal All directions			Castanheira do Vouga (Águeda) FR	
Ois do Bairro All dir.				
Barrô (Águeda) E/W			**Barrô** (Águeda) FR	
Fermentelos N/S (but with ecos from E/W)	**Fermentelos** (near chapel Nossa Senhora das Febre)		Espinhel (Águeda) FR	
			Agadão (Águeda) FR	
Macinhata do Vouga W/E			**Préstimo** (Águeda) OB	
Préstimo E			Palmaz HWA	
Recardães W/E			S. João de Loure FR	
Alquerubim E/W			**Alquerubim** FR	
			Fermelã FR	Portela (Sever do Vouga)
Sangalhos (Anadia) W/E			Requeixo FR	Sanfins (Sever do Vouga)
Vilarinho do Bairro N/E and E/S			**Talhadas** (Alfusqueiro river) FR	**Talhadas**
			Eixo FR	
			N. Srª Apresentação (Aveiro) UD	**N. Srª Apresentação** (Aveiro)
Cacia W/E			**S. Miguel** (Aveiro) HWA	**S. Miguel** (Aveiro)
Mamarrosa E/W				
Vera-Cruz (Aveiro) W/E	**Vera-Cruz**		**Vera-Cruz** (Aveiro) UD	**Vera-Cruz** (Aveiro)
				Aradas (Aveiro)
Vila Nova de Monsarros W		**Vila Nova de Monsarros**	**Vila Nova de Monsarros** HWA	
		Covão do Lobo	**Covão do Lobo** MD	
Oliveira do Bairro W/E with effects of N/S	**Oliveira do Bairro** S. Lourenço do Bairro		**Oliveira do Bairro** MD	
			Ventosa do Bairro MD	

Legend: N – North; S – South; W-West; E-East; UD – increase and diminishing level of rivers; HWA – High water agitation of the river; FR – Flooding (river); MD – Momentary drying of the water of fountains.

Table 4.1 – Table of localities with damages from the 1755 earthquake [credits Alice Tavares]

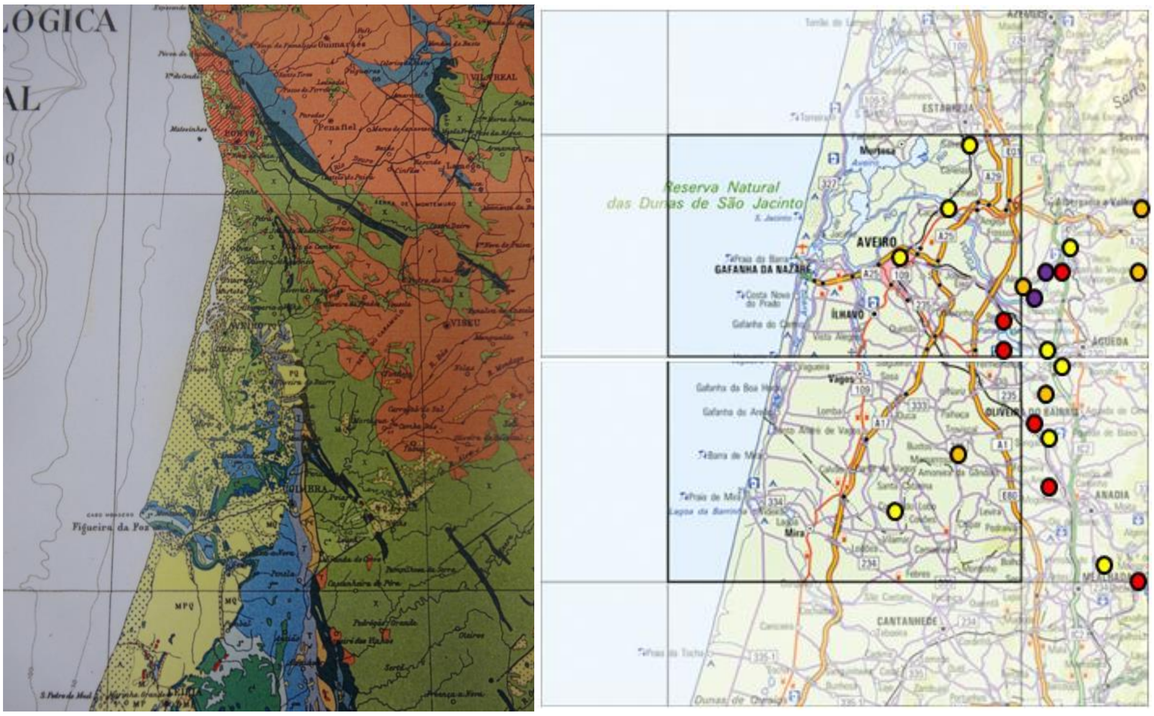


Figure 4-85 - Map of Aveiro region and affected area near the Fault Porto/Tomar [credits Serviços Geológicos de Portugal]; Legend: Red- vertical movements; orange – "liquefaction"; yellow – strong impact felt.

Every survey showed that the earthquake was felt in the region. Although in some areas it was felt more strongly than others. The first point to highlight is the fact that the direction of the earthquake movement was identified differently in some of the regions. Considering that the epicentre of the earthquake was in the south, in the sea, the expected direction was North-South/South-North. Unexpectedly, in some areas it is identified as West-East or East-West. On the other hand, descriptions identifying a vertical movement of the ground are more in line with a closer epicentre rather than the known distant epicentre of the 1755 earthquake. These two aspects were analysed and identified on the geological map and taking in consideration the information of: Teixeira C et al. (1962 a/b, 1976 a/b); Barbosa B et al. (2008 a/b); Soares A et al. (2007 a/b); Gonçalves L (1980 a/b). Although further studies need to be conducted by specialists, a concentration of the indicated events is observed in a specific region with a North-South direction, in the inland region from Vale de Cambra, passing through Águeda and continuing through Anadia, having a similar direction to the probable tectonic fault of Porto-Tomar. From this, we can raise the hypothesis of the impact of the distant earthquake on tectonic faults crossing near the region, which is a very

interesting topic for future research. Nevertheless, as the national geological map is not at present complete for this region, this does not contribute any more to the present analysis. This alignment of Vale de Cambra-Anadia is the area where all the potential descriptions of liquefaction are located, with the following descriptions (translated from the Portuguese):
- "…two pieces of land opened up and jetted black mud with vapours as if boiling during the earthquake and then closed" (Nossa Senhora das Febres, Fermentelos);

- "after the earthquake some cracks in the ground were seen nearby to the Vouga river" (in the local Vila Verde);

- "the river, the deeper sites sinking in the center, so it seemed as if wanted to merge" (Vera-Cruz, Aveiro);

-"crevices opened in the earth to reveal clay; (S. Lourenço do Bairro);

- "the earth opened up and started running water and green foam which soon after dried up" (Oliveira do Bairro).

Even considering that some of these descriptions may not be liquefaction events they were indicated on the map and almost all of them are in the same North/South alignment with the inland region. Taking into account that the noted areas are mostly along the transition area of the *Varisco* region/platform in an area with two different geological formations of different ages (Teixeira C et al. 1976), it is possible to recognize the effect of the type of soils but also of the nearby tectonics. From the aspects described for this specific region related to the topics mentioned, the areas of Pateira de Fermentelos and the estuary of the Vouga river should be analysed in the future. Furthermore, it is necessary to address the changes in the configuration of the coastal lagoon, Ria de Aveiro, and the estuary of the Vouga river that changed through the centuries and whose boundaries in 1755 were not the same as the present day. Although the seaquake was felt in the region there are scarce detailed descriptions in the documents analysed of the type of damage for this coastal region. This is especially evident for the constructions on the seafront. This is probably due to the small number of constructions along the seafront (most of them belonging to fishermen, probably secondary) and all the ancient towns and villages were in a second line after the lagoon strand, which can explain the minimal effect of the seaquake. Although along the coast there were small fishermen's buildings, the fact that the event occurred during the winter and at the weekend on a holy day can explain why there was no report of deaths on the shore. Probably these small constructions were made of timber (similar to the typical timber houses of Costa Nova and Mira) and being of very low cost was not reported in the damages. Nowadays this line of the coast is densely occupied with housing and secondary residences which increases the current risk. Nevertheless, in inland regions there are descriptions about the strong noise from the sea and the unusual behaviour of the water in rivers, rising higher than usual. There were other reports of the strong smell of sulphur in the days leading up to the earthquake in Macieira de Cambra (Vale de Cambra), Requeixo (Aveiro) and Covão do Lobo (Vagos). There were also relevant observations of pavements rising in the location of Avelãs de Cima (Águeda) Pinheiro da Bemposta (Águeda), Fermentelos (Águeda), Nossa Senhora da Apresentação (near the Vouga river, Aveiro), Covão do Lobo (Vagos), Ventosa do Bairro (Mealhada) and Casal Comba (Mealhada) during the earthquake.

Descriptions of the expected wave-like movements of the ground were more clearly identified in the parishes of Macieira de Cambra (Vale de Cambra), Macinhata do Seixa (Oliveira de Azeméis), Barrô (Águeda), Cacia (Aveiro), Requeixo (Aveiro), Mamarrosa, Ventosa do Bairro (Mealhada).

Although several parishes described that, despite feeling the earthquake, building collapse or severe damages did not occur, they explained this fact by most of the buildings existent at the time being just one or two storeys (Table 4.2). Most of them identified some damage to the tallest buildings such as churches, namely to bell towers and front façades. They also mentioned the ringing of bells without any human action due to the movement of the tower, which reveals the strong acceleration that the tower had experienced. There is also a description compatible with the expected action of the tie rods in a church. The use of these elements in churches can also explain why they did not collapse, despite the strong movements of the walls as mentioned. They explain the descriptions of the collapse of chapels as being due to their poor state of conservation. Nevertheless, in relation to the houses that partially or totally collapsed it should be emphasized that they do not mention the state of conservation and most of them belong to areas of stone masonry. The only exception was the area of Aveiro (mostly in the actual city centre), where it seems that the type of silt soil eventually explains this particular situation of damage. Continued research will highlight these interesting aspects.

A reference specifically identifying adobe constructions is mentioned in the survey response for Vagos explaining that damages were not observed in these buildings.

LOCALS WITH DAMAGES EFFECTS BY THE EARTHQUAKE OR STRONG MOVEMENTS OF THE CONSTRUCTIONS

STRONG MOVEMENTS OF THE CONSTRUCTION WITHOUT COLLAPSING	CRACKS IN THE WALLS AND ROOF DAMAGES	FALLING OF ELEMENTS OF THE FAÇADES OF CHURCHES / CONVENTS	PARTIAL COLLAPSE OF BUILDINGS
Cepelos (Vale de Cambra)	Aguada de Baixo (Águeda)	Aguada de Cima	Barrô (Águeda)
Macieira de Cambra	Macinhata do Vouga	Lamas do Vouga	Lamas do Vouga
Ossela (Oliveira Azeméis)	Alquerubim	Préstimo	Préstimo
Vila Chã de S. Roque	S. João de Loure	Avelãs de Cima	Recardães
Águeda	Arcos (Águeda)	Amoreira, Sangalhos (Anadia)	Valmaior (Águeda)
Espinhel (Águeda)	S. Lourenço do Bairro	Arouca (convent)	Espríto Santo (convento of St Domingos, Aveiro)
Fermentelos (Águeda)	Vila Nova de Monsarros	Fermelã	Vilar (St Amaro churche, Aveiro)
Lamas do Vouga	Vilarinho do Bairro	Casal Comba	Nossa Senhora da Apresentação (Aveiro)
Macinhata do Vouga	Aradas (Aveiro)	Murtosa	S. Miguel (Aveiro)
Segadães	Espírito Santo (convent of Jesus and St António, Aveiro)	Bunheiro (Murtosa)	Vera-Cruz (Aveiro)
Alquerubim (Águeda)	Casal Comba (Mealhada)	Pinheiro da Bemposta	Eixo (Aveiro)
Branca (Águeda)	Luso	Oliveira de Azeméis	Castelo de Paiva
S. João de Loure	Ventosa do Bairro (Mealhada)	Vila Chã de S. Roque	Santa Maria da Feira (convento of Espirito Santo and dome of Santa Casa Misericordia)
Ancas (Águeda)	Macinhata da Seixa	Oliveira do Bairro	Cucujães (Monastery of S. Martinho do Couto)
Aradas (Aveiro)	Oliveira de Azeméis	S. Cristóvão (Ovar)	S. Cristovão (domes and walls)
Fermelã	Mamarrosa	S. João da Madeira	Talhadas
Casal Comba (Mealhada)	Oliveira do Bairro	Talhadas	Paradela
Buçaco (Luso)	S. Cristovão (Ovar)	Roca (Sever do Vouga)	Pessegueiro do Vouga
Ventosa do Bairro (Mealhada)	S. João da Madeira	Sanfins (Sever do Vouga)	Roca and Sanfins
Oliveira do Bairro	Covão do Lobo (Vagos)	Roge (Vale de Cambra)	
Covão do Lobo	Roge (Vale de Cambra)	Vila Chã (Vale de Cambra)	
		Vila Cova de Perrinho (Vale de Cambra)	
		Junqueira (Vale de Cambra)	

Table 4.2 – List of locals with damages by the earthquake (1755) [credits Alice Tavares]

The descriptions of damage identified in churches reveal that these were the most affected buildings. The general records of damage with no further identification or description were not included in this list. Nevertheless, we can see the type of damages that occurred and evaluate if the strengthening measures in traditional construction can diminish these effects.

In relation to the type of damage caused by the earthquake, in addition to the ones mentioned in the above tables, the following were described:

Foundations – affected due to ground movements

Walls – cracks (clearly mentioned in twenty-five parishes, some of them severe):

- out-of-plane movements of the walls (mentioned in at least five parishes)
- the walls separating at the corners (mentioned in at least five parishes)
- opening of joints (stone masonry) and in the principal arch of churches
- change in position of stones, elements of the façades or the entire upper part of the belfries (mostly in churches or convents)
- breaking of stone lintels with the displacement of one part

Timber structures of floors and roofs – strong timber cracks (sound)

- separation of the timber structure from the walls (mentioned in at least five parishes)
- sliding of the timber structure of the roof beyond the limits of the walls

Vaults (churches and convents) – cracks (mentioned in at least five parishes)

Roofs – sliding of tiles on one side of the roof

- collapse of the roof.

Having identified the forms of damage, it should be emphasized that most descriptions compatible with out-of-plane movements of the walls belong to buildings in the inland region of the district (Águeda, Valmaior, S. Martinho do Couto in Cucujães and Oliveira do Bairro) ; similarly for the phenomenon of bell ringing due to the movement of the tower (Vila Chã, Roca and Sanfins) or the shifting position of the belfry of the church at Feira.

The most frequent forms of damage described above show a common link – the importance of connection:

- between the timber structures and the walls;

- between the walls, especially in the corners;

- between the vulnerable areas around openings and singular elements.

Now the type of damages should be compared with the type of strengthening measures adopted, noting that we cannot directly associate one to the other at the present time, but we can evaluate if the measures can improve the system and make it more resilient to earthquakes. Again, the type of measures chosen is also important because, independently of the earthquake problems, they may improve the mechanical performance of the construction and its durability. As several research studies on traditional construction systems (Costa A et al. 2008; Sousa Oliveira C et al. 1992; 2008; Lourenço P et al. 2006; Blondet M et al. 2007) have already indicated it is highly relevant that the construction acts as a whole in a seismic event. For this reason, it is important the connections between the timber structures (floors and roof) with the walls, but also between the walls and the foundations.

At the level of the roof structure, it is worth highlighting the original strengthening measures, observed *in situ*, which frequently use additional timber pieces and some metal elements. The main solutions that can be associated with an improvement to the overall performance are (not exclusive of seismic regions):

A. Use of a metal anchor (metal strips) connecting the tie beam of the truss to the loadbearing wall on both sides. This allows for a better link between the two structures to act as a whole, improving the energy distribution.
B. Use of an additional timber element (diagonal) that connects the timber wall plates (around the whole of the perimeter) in the corners of the building and onto the base of the roof structure. This contributes to the maintenance of a connection between loadbearing walls, avoiding the separation of the two planes.
C. Use of a small truss supported on the timber wall plates in the corner of the building. This gives a better distribution of the loads of the roof in the area of the corners of the buildings, additionally it can serve the same role as the previous element (diagonal).
D. Use of timber tie beams or tie rods connecting opposite walls. In some cases these tie elements are at the level of the base of the roof structure (or the attic floor), but in other cases are positioned slightly lower. The decay of timber tie elements can be overcome by the use of metal tie rods which restrict the out-of-plane movement. However, if there are errors in the placement of these tie rods they may not fulfil this objective, due to their lower position, farther away from the level of the roof structure.

This led to higher movements in the upper part of the building with two possible results:

- The sliding of the roof structure above the limits of the walls, observed in the above-mentioned earthquake event;

- Cracks in the walls, mostly in the area around the insertion point with a partial separation of the two walls above the level of insertion. Out-of-plane movements of the walls can lead to the collapse of the roof structure.

E. Use of timber elements to increase the rigidity at the apex, other elements are added to maintain the proper alignment of the apex**.** It also includes elements for the maintenance of the position of the end of the apex through a strut connecting the wall to the end of the ridge beam.
F. Use of metal strips connecting the principal purlins to the loadbearing walls; sometimes they are interior walls that reach the level of the roof. It has the same purpose improving the connection between the two structures (roof/wall).

At the level of the structure of the floors, regularly spaced tie rods were also used connecting opposite walls. Again timber elements (tarugos), regularly spaced (usually 0.5 m apart), were used to help the distribution of the loads of the floors along the walls. The distribution of these elements improved the mechanical behaviour of the floor structure; however its use decreased over time.

Although the Lisbon regulations of the time (from 1756) prohibited any element protruding from the roof, allowing initially only the kitchen chimney, it is not possible to draw precise conclusions about this. The later buildings in some cases present small towers used as observatories. Nevertheless, a similar restriction was also imposed in Calabria (Italy) in 1784, after another strong earthquake, forbidding the construction of cupolas and steeples on churches (Barucci C1990). In fact, most churches of the Aveiro region had problems with decorative elements in the front façade and in the bell towers, several times with the collapse of these elements. For this reason, all these elements should be assessed and preventative measures should be taken in the present day.

Finally, we discuss the role of reinforced concrete (RC) ring beams in adobe construction to try to understand whether they improve the behaviour of the building in a seismic event. These ‘ring beams’ were normally continuous and played a double role, namely distributing into the walls the vertical loads from the roof and paved areas, and possibly increasing the resistance of the walls to out-of-plane movements. The loadbearing component was still the adobe masonry. If properly adapted, this reinforcing measure can prevent out-of-plane deformations, and consequently roof collapse and building corner failures, typically observed in traditional constructions (Tavares A et al 2012a). The use of ring beams has been common since the 1930s in adobe construction in Portugal, where RC beams were connected to RC beams above the interior walls, unifying the interior structure with the exterior. However, reinforced concrete ring beams in earthen buildings have also been used in recent constructions around the world, as in New Zealand since the 1980s (Tipler JF et al. 2010). The Turkish Building Regulations - 1998 actually refer to such a procedure by stating that ‘masonry foundations should be built with reinforced concrete footings and lintels’(Akan A 2004). The use of reinforced concrete elements in adobe construction was also applied in Peruvian rural community housing following the 2001 earthquake in Moquegua (PREDES 2001). The use of ring beams or lintels, or even thin slabs of reinforced concrete, in adobe construction was common in the 1930s in Portugal (Tavares A et al. 2012a; 2012c), although they were very thin and were not intended to be a measure to improve the seismic performance of the structure (Tavares A et al. 2013). Reinforced concrete was a relevant source for Modernism, and its widespread use continues today, despite some controversy over architectural designs for seismic regions. Particularly in relation to adobe construction, it is necessary to emphasize the related problems of material incompatibility and the different mechanical performance between adobe brickwork and reinforced concrete elements with different rigidity. Reinforced concrete ring beams should be constructed evaluating the possible sliding effect and disintegration of the brickwork wall. Again, due to differences in rigidity between masonry and reinforced concrete elements, a local strengthening of the upper part of the wall might be required (Frumento S. et al. 2006 pp 4), as occurs in adobe construction in the Aveiro district.

4.7. Final remarks

All the above-mentioned problems observed in surviving earthen constructions seem to be easy to understand and to prevent. However, in practice a high number of problems were recorded, some of them due to incorrect interventions by professionals or owners. Additionally, a succession of building regulations presented problems as they were not adapted to this traditional system of construction. It is interesting to see that some of the ancient treatises (dating from the 15th century) already indicated some of the requirements to avoid defects and to promote the durability of the construction (see chapter 3).

This research concludes that there are six main areas of research that need to be carried out:

- Assessment of the impact of xilophages in the decay of the built heritage, mapping and monitoring the situation. This should give guidelines for the control of some pests.

- Assessment of the material and technical lack of compatibility in relation to recent interventions. In particular, the impact of the rehabilitation interventions on the preservation of authenticity and integrity of the traditional buildings should be assessed.

- Study more effective solutions that can be applied to old adobe buildings in terms of waterproofing barriers in existent buildings.

- Study of solutions that can improve thermal conditions and comfort without damaging the authenticity of the ancient buildings, namely without introducing changes to the materials and configuration of the facades and roof.

- Study the resistance capacity of adobe walls that have been subjected to fire events, and see if they are able to be used in a reconstruction process.

- Study the effect of the historical 1755 earthquake in the region and possible additional effects from the tectonic faults that cross the region.

5. THE INTERNATIONAL PROPOSALS AND RESEARCH CHALLENGES TO MAINTAIN CULTURAL VALUES

5.1. Introduction

This chapter reflects on the solutions presented in the ICOMOS reports from different countries in relation to heritage at risk. From this report, only information more directly associated with historic centres, vernacular architecture and civil architecture was used. This information makes it possible to conclude which measures are more appropriately associated with the protection of adobe heritage, the case study of this research. This chapter presents a proposal for change in the strategic criteria of Sustainable Integrated Conservation, adopting this concept to the adobe heritage to achieve better results. It has information from Tavares A et.al 2013c.

The research also continues to follow the guideline that knowing the past can lead to achieving answers for the future. Based on this idea, three different approaches were conducted to address major issues that need further research. This investigation considered the following needs:

- deeply understanding the disappearance of the traditional ancient adobe construction and discovering if there were any types of Modernist buildings using adobe – an external innovation using local materials;

- understanding if thermal issues provided an additional reason for the disappearance of this system or if the new solutions from 1940-1950 were an improvement over traditional solutions with natural materials;

- discover if the waterproof barrier solution proposed by engineers during the 1940s using the natural material diatomaceous earth was effective. Further, discover the effect of this new material in controlling the effects of salts in processes of rising damp.

5.2. International proposals to overcome the loss of built heritage

5.2.1. Introduction

The identification of problems in relation to the different sectors of built heritage was discussed in chapter 2. This earlier evaluation of the problem took the perspective of Sustainable Integrated Conservation and showed that a huge gap is present in almost all of the sectors in terms of the planning level. Although at a policy level, the lack of decisions, planning and implementation were major problems that compromise effective integrated conservation, the problem at the planning level is at the heart of the strategy. In addition, the lack of coordination between almost all of the sectors makes it clear that to surpass these problems, the proactive involvement of all of the sectors involved will be necessary at the planning level.

Although the scheme of Sustainable Integrated Conservation presents a highly relevant approach, this work considers that on the planning level, it is missing the topic of research. Research is highly important because this knowledge should be the base of many of the decisions at this level, and there are huge gaps that can compromise any strategy if they are not properly and sufficiently addressed.

5.2.2. Selection of main proposals of ICOMOS researchers to surpass the Conservation problems

To specifically understand what measures were noted for overcoming the lack of protection and conservation of the built heritage, data from the ICOMOS and UNESCO reports on this subject were selected from 35 countries for the period from 2000 to 2014 from the following countries (ICOMOS, UNESCO 2000-2014): Australia, Bolivia, Bulgaria, Canada, China, Colombia, Côte d'Ivoire, Cyprus, Cuba, Czechoslovakia, Ecuador, Egypt, France, Georgia, Italy, Iran, Japan, Lithuania, Macedonia, Mali, Malta, Myanmar, Nepal, New Zealand, Panama, Peru, Republic of Slovenia, Romania, Slovakia, Turkey, Uganda, UK, USA, Venezuela, Yemen and Yugoslavia.

Reports are analysed instead of the general guidelines of these international organisations because the problems analysed in chapter two showed a discrepancy between protection and conservation theory based on the situation in heritage sites. For this reason, this study prefers to analyse the indicated solutions for problems detected in the field. This analysis will focus on civil architecture/vernacular architecture because it is more closely associated with the case study of this research: the conservation of adobe building strategies.

- historic centres
- agro-industrial environment
- vernacular architecture

The main subject proposals are synthetized and divided into the identified topics: Strategy, Planning, Implementation, Monitoring and Evaluation. From these topics, it is possible to see that concerns with the conservation philosophy are almost absent from the reports, perhaps because all of the guidelines on this subject are addressed by ICOMOS and no changes are being discussed for this type of document. The same is also true for Monitoring and Evaluation issues: there are very few recommendations on these subjects. The primary recommendations and proposals relate to Strategy, Planning and Implementation and are as follows.

5.2.2.1. Strategy

Prevention and proactive measures – main international proposals:

- Prevent further deterioration. Develop legal protection and protection mechanisms—law and governance management protection mechanisms need to be updated in the form of a specific site law (including detailing protective measurements, enlarging boundaries and creating a buffer zone).
- Create a Strategic Regeneration Framework. Support sustainable social and economic development under integrated conservation. Sustain the outstanding universal value of the property over time; increase regional and international awareness of earthen architectural heritage. Analyse the townscape characteristics and develop constraints using

clear regulations that establish prescribed heights for buildings. These problems demand several parallel approaches: a systematic mass media campaign; research to promote investments that are sensitive to the preservation of Modern heritage; the intelligent and adaptive re-use of Modern buildings; the recovery of endangered heritage structures by finding a productive use for them; and the passing of new building codes and city regulations that are more adequate to the new context, including a more effective means of dissuasion. Finally, there is a need for visible and public support for a selection of projects to recuperate the Modern heritage, which could represent a paradigm and serve as an exemplar for additional preservation programmes. The launch of comprehensive surveys to document movable and immoveable heritage and to plan a long-term protection strategy for the promotion and development of education in the conservation of cultural heritage.

• National reorganisation and planning for various short- and long-term programmes to mitigate the potential risks of future disasters. Create a Strategic Emergency Plan, a Rehabilitation Plan for Historic Areas, a Revitalization and Safeguarding Plan, a Strategic Sanitary Plan and a Conservation and Management Plan. Provide assistance in developing local strategies. Create a management plan—within the management framework, the economic and social well-being of the inhabitants, their appropriation of the cultural heritage, and environmental sustainability should be strongly emphasised. Offer protection from the pressures of urban growth. This strategy should include taxation incentives to support the owners of cultural heritage property.

Furthermore, in the reports were presented more specific guidelines:

- Governments need to take responsibility for the conservation, management, and interpretation of their own heritage assets as an essential prerequisite for eliciting community involvement and support.
- The integrated assessment and management of natural and cultural heritage and a greater recognition and understanding of the need to conserve cultural landscapes is required at all levels of government and within the community.
- A certain degree of authenticity exists and could be augmented if the urban layout and traditional buildings are restored to more adequately convey the outstanding universal value. There is an urgent need to reverse downward trends.

- Restoration and sensitive re-use proposals are needed that recognize a continued role in the community; because most of these places are still in use and play an important economic role, they have been conserved.
- Effects on tourism should be minimised. It is important to adopt these plans quickly to avoid any further transformation or loss.

5.2.2.2. Planning

The international reports present the main proposals:

- Develop appropriate technical skills. It is urgently recommended that a multi-disciplinary survey be launched that targets geologists, archaeologists, architects at the historical monuments department, the research consultancy in charge of prospecting.

- Clarify specific long-term objectives – enlarge the buffer zone by approximately 500 m to assure the protection of the property. Address vulnerability to decay factors. Develop emergency measures to stop decay or maintain structural security. Delimit a buffer zone. Conduct building regulations/ sustained conservation actions in accordance with scientific conservation principles and standards. Guide design to minimize the risks in and around the property that future development might adversely affect its architectural quality and sense of place or might reduce its integrity. Guide adaptive re-use work for the building(s); research their architectural history.
- The integrated assessment and management of natural and cultural heritage and a greater recognition and understanding of the need for the conservation of cultural landscapes is required at all levels of government and throughout the community. The long-term challenges for the management of traditional buildings are to ensure regular maintenance to mitigate climate impacts and to put in place a long-term strategy to secure a sufficient supply of organic materials for their repair.
- Create a participatory Management Plan - encourage and assist in the restoration of buildings within designated areas of the property and guide short- and long-term actions. Define and launch a Rehabilitation Plan for the Historic Areas / a Conservation Management Plan / Regulations/ a Master Plan for Conservation, Rehabilitation and Development. Require detailed master plans for specified areas

and conservation plans for the individual buildings. Integrate corrective measures. Finance the implementation. Support a cultural tourism plan that balances social, economic, and educational needs. Ensure that the height of any new construction on the property does not exceed that of structures in the immediate surroundings; the character of any new construction should respect the qualities of the historic area, and new construction should not dominate but should complement the historic structures. A housing rehabilitation programme and an infrastructure improvement project will be conducted.

- For any proposed large-scale project, it must be confirmed that the proposed work will fit in with the character of the historic and natural environment.

Furthermore, interventions in cultural heritage should be regulated by the Municipality and by National Construction Regulation.

- Developing management instruments such as the Metropolitan Development Plan, which established basic guidelines for the protection and conservation of built heritage, interventions and projects related to the situation and to urban structure, environment, land use, transportation system, habitability and urban dynamics.
- Current inventory projects are making strategic progress by involving communities in identifying their own heritage places, reaching far beyond the recognition of monuments and sites by experts. Professional teams of conservation practitioners working closely with communities are forging new methods and opportunities for collaboration.
- Advancing conservation methodology and practice
- Preparing a prioritized plan for emergency repair and conservation/restoration measures for all structures
- Planning and designing urgent, mid-term and long-term activities to repair and strengthen damaged cultural heritage involving all those involved in the protection of cultural heritage (both government and non-government organisations
- Public education, the adoption of ‘smart-growth’ philosophies, the development of heritage tourism programs, the identification of public and private funding sources, and a strengthened commitment to preservation from political leaders are all needed to keep the region’s unique heritage from crumbling to dust.

5.2.2.3. Implementation

For the implementation of strategies (including research and technical support) it was emphasized the following issues:

- Emergency and active conservation implemented. Conservation Manual/ the publication of illustrated technical specifications and basic services to support conservation and rehabilitation. An established network of experts and institutions focused on the study, conservation and dissemination of sustainable architecture. A prescription of customary regulations, prohibitions and penalties. A conventional collaboration system for maintaining vernacular houses retained by residents. Actions to avoid demolition and to maintain the profitable character of the building. Routine repair work should be conducted by the owners and often through conventional collaborative efforts by communities using traditional techniques and materials. The local and national governments should provide both financial assistance and technical guidance. Consolidate the structure and prevent destructive processes (fissures) in the façade resulting from seismic activity.

- Close cooperation with the elected members of the territorial communities and their development partners. Implementation overseen by public bodies and management committees. Increased activity by some municipalities in implementing building codes for their historic centres. Enhanced capacity of local actors in the management and conservation of earthen architecture. A strategic and management planning framework, “Local Tourism Promotional Strategy and Management Planning Framework for Sustainable Development of Traditional Buildings.
- Co-ordinated programmes of education, policy and protection strategies
- A guide for tourism operators, heritage managers and communities.
- Practitioners need to develop methods to work more closely with communities and act as facilitators rather than experts when assisting the community to identify and conserve its heritage. •Prepare a preservation and restoration plan to restore and stabilize the gate approach and the surrounding area to facilitate exposure and public visitation. These should be followed by a comprehensive programme for the restoration, exposure and socialization of the monument. Implement multidisciplinary activities for the overall restoration and exposure of this remarkable monument, which will guarantee its sustainable protection and effective

socialization. Draw and implement plans for the overall preservation, restoration and socialization of the building.

- Specific regional and rural programmes are needed to promote the recognition of heritage and to actively assist with its conservation. Update and amend the existing plans for reinforcement, preservation and restoration.
- A full geodesic and photogrammetric documentation of the archaeological ensemble is currently in preparation. The protection of the monument requires the implementation of the following urgent measures: Complete the exploration, documentation and publication of results;

5.2.2.4. Monitoring

- Put a monitoring system in place.
- Conduct routine inspections.

5.2.3. Main conclusions

This assessment of the international proposals demonstrates that the reports are more focused on strategy, planning and implementation. However, considering the several proposals and their link with the difficulties identified in chapter two, this research concluded that the topics of Research, Education and Coordination should be emphasized in the framework in broader terms and not only restricted to some areas (Table 5.1).

Table 5.1 – Proposal of framework [credits Alice Tavares]

ACTIONS → AGENTS → INSTRUMENTS

SUSTAINABLE INTEGRATED CONSERVATION (SIC)				
INSTRUMENTS	AGENTS	ACTIONS	BARRIERS	INNOVATION
Technical	Productive sector	Assessment	Technical	Production
Legal	Public sector	Procurement	Market	Conservation
Economic	Research sector	Planning	Socio-cultural	Demand
Social	Third sector	Implementation	Linguistic	Management*
Research*	**Educational sector***	Monitoring	Philosofical	Cultural value protection*
Education*		Production	Legal/Regulation	Research*
		Prediction	**Educational***	Learning system
		Operation	**Coordination* management**	National Education
		Maintenance	**Research (lack)***	Instruments and Systems
		Evaluation		National Innovation system

* proposals of Tavares research to the model of Johansonn

5.3. Adobe architecture – the missing link of interaction with the Modern Movement in Portugal

5.3.1. Introduction

The knowledge about the last phase of the adobe architecture in the Central Region of Portugal is part of the debate on the role of architects, engineering and construction agents about the function of architecture and its relationship to the culture of a region. It includes reflection on ways to build cultural values, their protection, and the production of the future heritage, understanding this within a framework of social and technological exchange. It also coincides with a rich moment of national and international debate on architecture, the Modern Movement (International Style), and the minimum housing conditions and comfort

that have been an issue of concern in legislation in addition to the urban planning issues at that time.
This is a built heritage that is rapidly changing; it is often deeply altered or simply demolished. This raises debate about the level of protection that should be given to fairly recent buildings that are not understood by stakeholders as heritage. This is also the current debate surrounding the buildings of Modernism and the Modern Movement, which use current construction techniques such as reinforced concrete. This chapter will present the traditional typologies of buildings of adobe and the transitional solutions of the experimental phase of Modernism. This research supports the distinction between Modernism (between 1930-1945) with Experimentalism linked to traditional frameworks and the Modern Movement (1945-1955), with Experimentalism inside a new framework made by Ana Tostões (2002) in her doctoral thesis. However, in terms of the time periods, they are not adjusted totally to the reality of this region and begin a few years later. In some circumstances, Modernism can be extended to 1955, encompassing the assumption of authorship of non-architects. On the contrary, Modern Movement architecture involves only architects intervention.

There are difficulties in their protection, which is often achieved as isolated author enhancement of specific buildings or related to a referenced architect, especially in large centres (Lisbon and Porto). This research focuses on traditional construction that was contemporary to the Modern Movement and used an ancient construction material, adobe, despite the spread of the use of reinforced concrete and new structural conceptions. The globalisation of the use of reinforced concrete is often noted as the main reason for the disappearance of traditional construction techniques. However, this study concluded that this was not a significant factor in the first phase of decline and it was not exclusive or prevalent.

For this purpose, this study analysed more than 1.462 file processes for the period from 1922 to 1956 from the district of Aveiro in addition to in situ inspections with geometric data collection and photo records. Additionally, local newspapers of the time were consulted, interviews were conducted with elderly residents and historical and statistical literature about that period of time was consulted. A special focus was on data specifically from the cities of Aveiro and Ílhavo due to easier access to existing buildings, especially in Ílhavo.

This was one of the most significant areas of adobe construction. The last licensing process of adobe construction identified was in 1971.

This study also considers data for previous periods for a better understanding of the evolution process and regional base of influence. It encompasses private data files and surveys reports of the 1940s, comparing with the existing ancient buildings of the 1930-1940 period. The town of Ílhavo was selected for a more detailed presentation of the case study. Ílhavo is one of the few cities that contain adobe constructions from almost all the evolutionary stages and in perfect use since at least the 18th century (Figure 5-86). Comparative data were also included for neighbouring cities, highlighting Aveiro and Agueda. This methodology has shown what was actually transformed into constructive adobe systems in vernacular or civil architecture in relation to the impact of Modern Movement architecture. It also allowed understanding of the interactions between technicians and, equally importantly, the framework in social transformations. This evaluation has concluded that the most interesting period for this part corresponds to 1940-1956, so the data presented are mainly focussed on that period.

Figure 5-86 – Examples of residential buildings of Ílhavo [credits Alice Tavares]

5.3.2. Objectives, background and methodologies

5.3.2.1. Main objectives

The objective of this study is to show one of the possible approaches to an Integrated Conservation Strategy. There are several possibilities for study that can support guidelines for the enlightenment of the cultural value of traditional construction systems:

1. knowledge about the evolution of the construction system and its roots in the social, cultural, economic, resources and political management in a specific environment;

2. knowledge about multicultural links, such as regional, national and international influences, inside the same construction system;

3. knowledge about the shared manufactured skills, materials and technologies with other construction systems;

4. knowledge about the interaction between the evolution of the traditional construction systems and architectural movements or engineered solutions.

The research noted one of these possibilities, 4, in continuity with previous studies and with links with the work of other researchers (national and international). Because the last possibility is the most innovative and presents a huge gap in the national research involving adobe construction systems, it was the issue chosen to develop and propose for the cultural promotion of this type of construction based on research. This study also provides information to apply to future guidelines for the protection, rehabilitation and reuse of these buildings from the period of Modernism. This will help in the identification of the relevant elements that should be maintained and that are significant to understanding the evolution and longevity of this earthen architecture. There is a growing transfiguration of many urban centres and rural settlements where the *fachadismo* reigns and demolitions are used as a means of ‘regeneration’ without any reasonable technical justification. This more recent part of the history of adobe heritage is particularly vulnerable due to the lack of awareness of its value and lack of knowledge about its existence. In addition, it is assumed that many buildings are made of brick masonry when a high percentage of them are adobe constructions. This is another reason to conduct this study and to present the following conclusions.

5.3.2.2. Temporal and geographic environment background

In the period from 1940 to 1956, the architectural International Style/Modern Movement was in full progress in Europe, providing one of the most significant transformations of architecture and an almost globalised construction technique. This architectural movement was being developed on other continents with a strong impact and interplay with Europe. Even within the same country, the approach to architecture and the adoption of new materials were not consensual in the initial stages. In some cases, nationalism found expression in architecture. Whether by the imposition of rulers or by the free will of architects, the use of natural traditional materials obeyed other goals in addition to tradition.

The search for the monumental character and 'soundness' of the state favoured the use of stone, but the experimental purpose of the architects also potentiated the use of natural materials in the new framework of architecture to enhance textural or mass contrasts, among other goals. Once again, stone and wood were commonly used, especially in the initial phase of the Modern Movement. However, the question arises of what happened to adobe, which is a material that should be hidden by plaster and thus without the texture or colour expression of other natural materials imprinted on buildings.

This chapter will present the changes that occurred in this heritage of civil architecture.

5.3.3. Characterisation of adobe buildings of the Modernism period (1940 - 1956)

Many authors recognise the importance of the period at the turn of the 19th to 20th century to understand the changes that occurred at the beginning of the Modern Movement. However, the changes occurring during this period have revealed full awareness of the assumptions of the Modern Movement. It was in the 1950's that the Modern Movement was implemented more generally.

However, this is a process that did not occur simultaneously in all regions. This is the case of the chosen subject area, where the period that is considered Modernism occurred during World War II, maintaining the influence of Lisbon and Porto that was observed since the 1930s.

During the 1940-1956 period, buildings passed through previous licensing processes (authorisation to build), although there continued to be some spontaneous construction that was uncontrolled by the municipalities.

The 1946-1956 period in the Aveiro region retained many of the above references. However, it was processed with less experimentalism that involved adobe architecture. Instead it shows an introduction of a greater mixture with brick masonry and whose lines within the Modern Movement were already linked to the wide use of the concrete and brick system. In this regard, one should consider the evolution of the construction system described in chapter three.

The research concludes that during this period, the region included three lines of evolution with interesting aspects of influence. Thus, we have a first-line continuity with traditional construction conceived by technicians, a second line that involved the trial of Modernism but retained some characteristics of traditional construction and a third line that sought to break with the design space and symmetry in the façade plan of the traditional system.

One of the most interesting aspects found during the investigation is that the technicians responsible for submission of the proposal to license mimicked the traditional solutions of previous decades, sometimes without introducing changes in the typology beyond greater care in describing the infrastructure as sanitary (due to the imposition of urban regulations). For this reason, these solutions are presented in this subchapter as 'traditional' and not as vernacular.

However, these are the same solutions as those that are known as centenary. This is one of the aspects to be considered in the analysis of this region to avoid incorrect approaches or timelines. Many of the existent buildings with this typology are not centenary buildings, contradicting previous beliefs, but they are from this period (later 1940s). This is particularly true in less central areas of these towns and in areas of urban growth at that time, such as in some of Gafanha's regions (Ílhavo).

Traditional built typologies from the 1940s-1950s show the simplicity and reduced space of vernacular solutions of the past. This condition is evident in the statements of the engineers responsible for the report 'Survey on Portuguese rural housing' (1947), when dealing with the case of the rural buildings. This survey emphasises the minimalism of spaces as well as the low number of furniture pieces used, ironically indicating that there is no room to add more.

These traditional models reveal a house design as an 'inhabit tool' with nothing superfluous—only the bare minimum to eat and sleep and the normal association of the kitchen space with the fireplace.

The different traditional typologies of the time will be presented in this research to understand what occurs in urban areas and in rural areas. This analysis of the construction practices used establishes the basis for comparison with other lines of approach and thereby completes the experimental approach in spatial terms.

The smallest longitudinal model (Figure 5-87) is composed of three divisions with similar dimensions around 3.5 m x 3.5 m^2 located along the length lot. Similar models were found in the Alentejo but with guidance accompanying the front street. Models with only two divisions that the authors of the survey consider current in Alentejo arise in this region much more sporadically. Possibly this is due to the fact that, this was a region with incomes above the national average (PUI, 1945; CMI, 1945).

This building longitudinal typology, with three divisions, usually had the following compositions:

Urban - successive organisation of spaces with direct entry in the living room from which the bedroom can be accessed and, from this bedroom to the kitchen with the front to the backyard and a door to the outside. Depending on the width of the lot, this model could have only an exterior corridor to access the outer side street with an independent gate from the house at least 1.2 m wide.

Rural - the sequential organisation of spaces remains, with direct entry to the bedroom / living room, from which there is access to the kitchen and to an agricultural storage space that is connected or unconnected to the kitchen. The urban solution mentioned above is also observed in rural settlements.

The building typologies with common dimensions of 4.5 m by 12.8 m were mostly used by small families without children or with young children. Kitchens were usually located in the backyard due to fire safety reasons and because people worked in the backyard in subsistence farming.

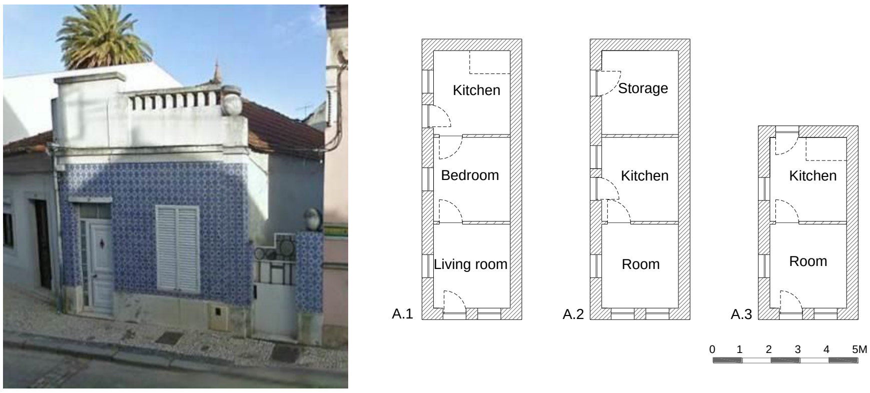


Figure 5-87– Example of a “traditional model” [credits Alice Tavares]

The model with an ‘L’ composition (Figure 5-88) is mainly located in rural settings and has three divisions with an identical functional programme as the previous solution, with direct entry through the room. In front of that was the side bedroom, followed by the kitchen to the backyard. There was also a variation in the L model with further development, which included the insertion of a barn space or agricultural storage in the front of the house and separated from the living space by a wide gate. The main entrance was directly into the living room with a detached kitchen facing the backyard, involving a distribution close to the longitudinal model.

Figure 5-88 – Examples of urban ‘L’ model and rural building of the region [credits Alice Tavares]

The compact model (Figure 5-89) with four divisions appears with great similarities in other regions of the country and with other construction systems, as in the Alentejo, despite the differences in the main façade. This is a model that tends to have the symmetrical façade that is characteristic and widespread. It has an almost square plan of 6.5 m x 6.5 m. The divisions may present an unequal depth.

Figure 5-89 – A traditional typology of adobe building and its variations along the time [credits Alice Tavares]

Finally, the compact long model (Figure 5-90) presents an organisational division usually of six parts, keeping the forward link between the spaces and entrance into the room, from this to the kitchen maintained with the front to the backyard. This is a solution for larger families with higher economic capacity.

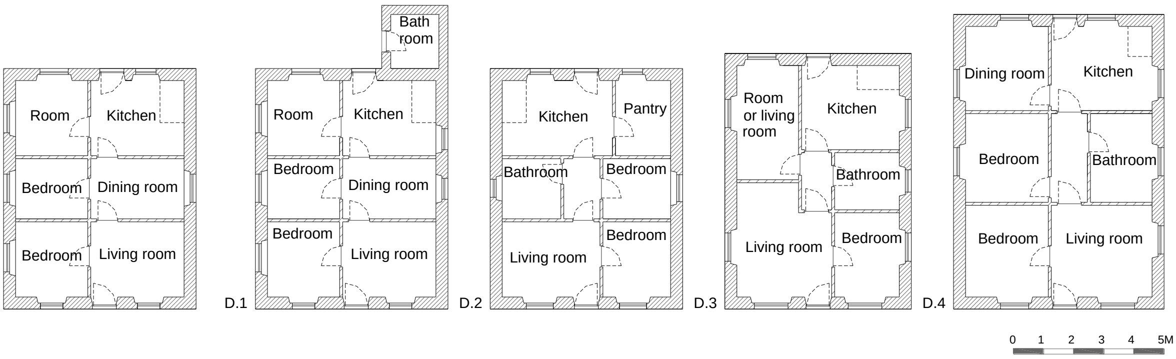


Figure 5-90 - Design plans of more compact solutions of residential buildings and their variations [credits Alice Tavares]

The most basic typologies in urban or rural contexts have similar dimensions and patterns for many different dimensions and fronts. Therefore, these characteristics were not associated directly with the configuration of the lot, and the building could be at the front or far from the street.

It is observed that traditional solutions are based on modular-based types (sizes between 2.5 and 4 m) and present with the largest dimension in the longitudinal direction of the lot. The function of the spaces can be versatile depending on the needs of the occupants, the number of occupants (possibly some temporary) and the lifestyle of the time. With the kitchen is frequently the family living space; this is usually the area with slightly larger dimensions. The room easily turns into a bedroom, again reversing the function when the household changed. This is one aspect to keep in mind when part of the population was dedicated to deep-sea fishing, many times with a long absence period or death of one family member.

The room space was limited in size and the location subdued to a place of passage and reception, valued for only the continuity in all solutions of the place of the windows to the main façade. From all these circumstances, it is concluded that older models persisted. They did not reflect the organisation of housing for leisure time or for social interactions inside the houses. The models presented above all a functionally minimalist characteristic. This aspect indicates another factor: these are solutions for an active population whose working hours are long, with few moments of leisure and whose moments of social interaction occur especially away from home.

The dwelling interior serves mainly for family reunions at mealtime and sleep. Note that most of the theatres or halls of parties that are built at this time do not belong to public bodies and serve the companies that manage them. Some areas, such as Ílhavo, are located either in the centre or in tourist places, such as the beaches. A very reasonable offer of spaces such as theatres, dance halls or ballrooms was greatly appreciated for the sense of community as well as leisure shared outside of the restricted core, again distinguishing this point in Ílhavo.

This is a small community whose documents indicate a basis for solidarity that distinguishes it from others, an aspect that also emphasises localism to justify the maintenance of traditional construction techniques. Literacy background and economic capacity are higher than in some cities in the district, which is referenced in the specification of the Urban Plan from the centre of Ílhavo (CMI, 1945) by architect Carlos O. Ramos, speaking on national comparison.

Thus as observed these models have an internal organisation of spaces based on a sequence, normally without a distribution hall, from one space to the other, and the room often sacrifices one of the spaces. This type of communication between spaces without corridors reveals a devaluation of individual privacy values. However, it accomplishes a building capacity to easily grow in the future from one model to another based on modulation. These allow the work to occur simultaneously as the housing models are inhabited.

Normally, these enlargement processes are justified by household growth, but the kitchen remains with façade in front to the backyard. Again, this process guarantees that the area of greatest risk of fire (the kitchen) is furthest from the living area and closer to the backyard well. In addition, it is maintained for those who work in the agriculture fields to have easy access to the kitchen from the backyard for meals, without having to enter the rest of the house. In urban areas, this change did not always occur this way; sometimes the kitchen was in the middle of construction with lateral access from the exterior corridor.

The prevalent transformations between different models were:

- **a.** From a longitudinal model with three divisions to an ‘L’ composition in rural areas;
- **b.** From a longitudinal model with three divisions to a long compact model with more than five rooms.

These extensions maintained growth based on modules and often without establishing distribution corridors.

The design of the spaces remains associated with traditional building practices, whose economy of means is valued, to also suit a timber industry that is still underdeveloped in the region (see Chapter 3 data). This often depended on measures and currents timber coming sections from other regions, including the north and within the district, to result in the most economical use of wooden beams. This constraint was responsible for the restricted dimensions of the spaces due to the average span of the timber beams. This aspect did not change for most buildings, even with the new regulations imposed by the urbanisation plans of the 1940’s, which implemented house fronts with greater width.

5.3.3.1. The evolution of the traditional model of housing by non-technical architects (civil engineers, technical staff of engineering, designers and building contractors) - 1940-1956

This study follows the work previously presented in the thesis of the author (Tavares A 2009), which addresses the role of different technical developments in the adobe construction system, the technical provenance and the distribution of influence. Note that in the absence of sufficient numbers of architects in the country to meet demand, it was accepted by municipalities that non-architects signed licensing projects for approval, as civil engineers, technical staff of engineering, designers and building contractors.

The description of 'traditional' models under construction at this time and subscribed by non-architects shows which elements were introduced by them. This was a period when some of them tried to establish proximity to modernist languages (Figure 5-91).

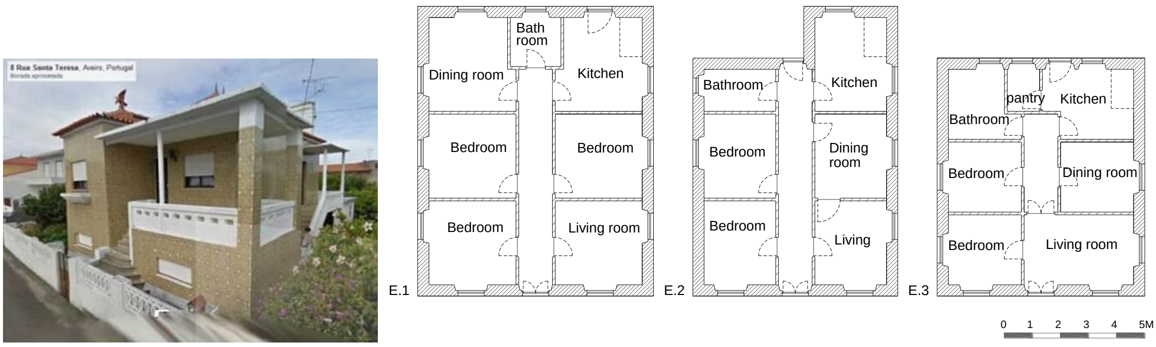


Figure 5-91 - House with central corridor and a terrace at the front and variations of similar type of solutions without terrace (design plans) [credits Google Earth – photo and credits plans - Alice Tavares]

Contingencies are associated with legislative measures in the areas of public health and public law (as already explained) and to raise awareness of the concept of privacy and personal space. Additionally, an attempt at separation between the sexes was gradually leading to new solutions. The new public health concern has forced the inclusion of sanitary facilities in the housing programme. So this space insertion was no longer just another outside division in the backyard which was sometimes precarious and had no connection to the urban sanitation system. During this period (1940-1956) these housing models had larger deployment in more rural areas or in new areas of the expansion of cities along the new roads to the periphery.

It is observed in most of the solutions presented by these technicians that there is a constancy of housing characteristics such as the following:

• great metric regularity of spaces so the dimensions of these spaces are the same independently of the functions (by civil engineers);

• adopting traditional models, including adjoining toilets usually in brick masonry construction and with direct access from the outside. Only at a later stage is it incorporated into the interior, initially as a space only with a sink and toilet and significantly later as a complete bathroom. The kitchen usually maintains a traditional position, but sometimes incorporates the storeroom that may take advantage of the attic stairs, as in previous cases;

• introduction of corridors or small atria distribution in the traditional typology solutions. It is considered that the solutions with central corridors that existed since at least the late 19th century and that were mimicked belong to the same buildings that had technical support or influence not via vernacular transmission in the past. This is a solution that was progressively adopted for traditional construction and took root, especially in buildings for people with greater economic capacity. However, in this study period (1940-1956), the buildings constructed with central corridors were not prevalent. Most of the solutions take a very short hallway or small atrium in the centre of the distribution, thereby enhancing privacy levels but also increasing the functionality and implementation of the mono-spaces. The same is true in the narrowest buildings, sometimes using corridors without lighting other than the zenith on the tops, an aspect that was also apparent in the past. However, legislation and regulations of urbanisation plans have rejected solutions for rooms without natural light.

• greater separation between the living spaces and areas associated with agricultural activity, which was not so defined in previous periods.

• another aspect that has gradually begun to be widely used, especially since 1946, is the retreat of the main façade of the plan to incorporate a covered space in the entrance area. This was a model adopted at least in Art Nouveau and Art Deco houses, and which was used by people with greater financial capacity. There is an imitation of this type for buildings with two floors and without the characteristic decorative elements of the previous periods. This incorporation of the covered entrance in traditional construction accompanies an influence of the lines developed in architecture that value the demarcation of the main entrance in relation to added entries.

This is an interesting aspect because it was commonly adopted for the construction of the first floor, although the design of the inner base organisational structure almost did not change. It maintained quarters for the owners or a bedroom / office for larger buildings (a situation similar to other regions and to prior periods). The construction of houses with more divisions can be progressively observed. This may be associated with the fact that this area, unlike other rural areas, maintained its population retention capacity. This was due to the national migration from other regions of the country's interior or inside the Aveiro district.

This covered entrance space goes beyond the symbolic function and breaks the traditional symmetry of the façade with the function of improving comfort by protection from the rain and sun (Figure 5-92). It should be noted that most of the solutions remains the direct access to the living room without receiving atrium space. The living room still has reduced dimensions, which shows once again restricted social interaction, more associated with conversation at the door or resting on the inlet bank. Note that these models appear in both rural and urban environments, distinguishing a larger number of cases with two floors in the city centre or in the centre of the parishes.

Figure 5-92 - Alterations to the previous models with the addition of a terrace [credits Google Earth –photo and credits plans: Alice Tavares]

Another featured aspect is the type of solution adopted for the construction to rent for low income families or for vacation. Interestingly, the solutions adopted resort to traditional models (especially the longitudinal model) with or without side corridors, focussing on the economy of means. These buildings are located mainly within the backyard with access from the side gate of the main houses (that were located in front of the lot). In the summer, the beaches of Costa Nova and Barra attract a growing tourism. These were also the base models applied at least during these two decades by private investors who guaranteed the supply of housing for rent for people with low incomes in city centres. This was a supplementary source of income of the wealthiest families and a contribution to important social solidarity to the city or the necessary home workers.

In the construction expansion process (especially during the 1950's, a period of adaptation of existing buildings to new living needs), these technicians maintained their connection to traditional roots and usually used an L typology or U typology with the exterior central courtyard open to the backyard.

At the time, the most 'U' (central yard) typology, of the existing buildings had this configuration because they were expanded over time and it was not their original shape. Some of these extensions are later than 1956. This aspect contradicts what commonly is presumed about these existing buildings with the setting (U or O), considering these configurations as original, which is not the case. So, one cannot generalise their area or construction time.

5.3.4. The influence of the technical staff of Porcelain Factory Vista Alegre (VA), Ílhavo

The collection of data in the VA archive, in the city of Ílhavo and in situ surveys identified the evolution of the use of adobe in this region. The references introduced by the VA technicians differ from that proposed at the time. Whether this VA influence covered other municipalities is still under study. The Porcelain Factory of Vista Alegre with its working-class neighbourhood, mostly built in adobe, included an infrastructure that provided a good level of autonomy from the city. This shows a very relevant moment of the adobe architecture.

Several authors have addressed the built VA Factory, but studies on the influence of VA outside its boundaries have been addressed by the author only in a previous thesis. To better fit the technical capacity in terms of adobe construction evolution, some data are summarised and supplemented by other references of the author. The importance of VA relies on an innovative and wide conception of the industrial settlement involving adobe construction. The VA was the first porcelain factory built in Portugal and was founded in 1826 without even achieving knowledge of the proper process of porcelain manufacture (Figure 5-93).

The enterprise founder (José Ferreira Pinto Basto) had several other companies in the country with headquarters in Lisbon and Porto and also invested strongly in buying properties in government auctions. This entrepreneur, who had a fleet of boats for the trade with Brazil and India, was a holder of the national tobacco trade exclusive for 15 years and porcelain for 20 years. The entrepreneur recruited or sent experts to train in France or England, bringing specialised foreign technicians to teach the chemical, paint and mechanic industrial techniques.

The factory has always been a pioneer in introducing new technologies, as it was the case of energy production and research in the production area. It employed families, ensuring that everyone had the right to education, which was promoted through school and the teaching of music and painting, besides childcare. The management of an industrial and working-class neighbourhood park involved a technical team of civil engineers, technical staff and engineering designers who were also responsible for planning the maintenance of buildings, expansion work or new construction.

Figure 5-93 – Vista Alegre Atlantis Factory [credits of Vista Alegre]

This team had contact with architects from Porto and Lisbon (A. Brito, Vasco Regaleira, others), which provided architectural projects, sometimes only pencil drawings, which were adapted to the adobe construction site taken by the factory team. The factory management team usually provided the adobe for builders who were hired. The housing models showed in this subchapter are from technical staff of Vista Alegre or technicians with close connection to the management team and factory owners (family and professional relationships), including design for private properties out of the factory perimeter.

The zone of influence was not restricted to the vicinity of the VA. There are examples in the city centre, in the different Gafanha's areas (particularly in Gafanha da Nazaré), in the Ermida and in Vale de Ílhavo. References to the architect Raul Lino should be considered relevant to this reading, and the influence of this architect is not restricted to the order on the porcelain decoration for the VA.

Also note that the diversity of the housing typologies in the VA (Figure 5-94) has allowed the technicians to follow the changing of the national architecture proposals. For this reason, in the early 1940s, proposals for licensing moved away from traditional models that other technicians of the region usually had adopted.

Figure 5-94 - Buildings of the residential area of the Vista Alegre Factory, Ílhavo [credits Alice Tavares]

The main difference between their proposals is the adoption of experimentalism to the internal organisation space. It has a spatial sequence with greater individualisation of the stairs and especially with the cutting of the perimeter, leaving the rigidity of the rectangle or square of traditional construction. This approach found a way to introduce shapes that can be associated with Modernism, although obeying adobe constraints and market sections of wood for the desired spans.

Thus, while adopting the constructive system of adobe, elements are introduced that accentuate the asymmetry of façades, sometimes understanding each as an individual defined space with cut-outs and transition elements. The other side that is unexpected is the removal of eaves that were used to a great extent in the building stock of the factory, which was connected to the 'family sense', which the VA managers wanted to promote. Therefore, it was proposed to replace entablements around the perimeter of the building to find the most Modernist language without giving up the roof.

The case in the design of the entry is one of the aspects considered, either through partial extension of the roof slope, as was the case in some of the schools proposed by *Plano dos Centenários*, or through very thin slabs, in some cases with significant projection. Some of these buildings now find themselves with significant changes that hinder their association with the original design. This can include the later introduction of roofs or the introduction of industrial tile walls of poor quality, whose texture distorts the reading of the building.

Another aspect that distinguishes their solutions is the introduction of curved walls on the façades. This is usually to configure enter spaces or specific areas of the living room. Even, the author (architect) of the urbanisation plan criticised those solutions, believing in the risk of constructive problems associated. In fact, the experience with round plans of the wells made with curved adobe blocks gave some confidence to these technicians for use in buildings, and the strategy was repeated several times.

Another aspect that is more in line with the workers of the VA neighbourhood reveals references to the architects Raul Lino and Rogério de Azevedo, with roofs and eaves and entries marked by arches (Figure 5-95, Figure 5-96, Figure 5-97). Volumetric recesses in plan, fences and exterior reinforced concrete stairs were painted with white lime with lines in yellow ochre, which is also observed in some periods in Alentejo buildings. These are other characteristics that contrast with the strong colours applied to the buildings in the city centre that are connected to the distinctive colour of the boats of the owners. Nevertheless, the architectural plans show some references to some of the VA working-class neighbourhood models, as concerns about the case of the central minimal atrium of distribution in dwellings, in an experimentalism process involving also living comfort.

Figure 5-95 – Different proposals of technicians associated to Vista Alegre Factory [credits photos: Google Earth]

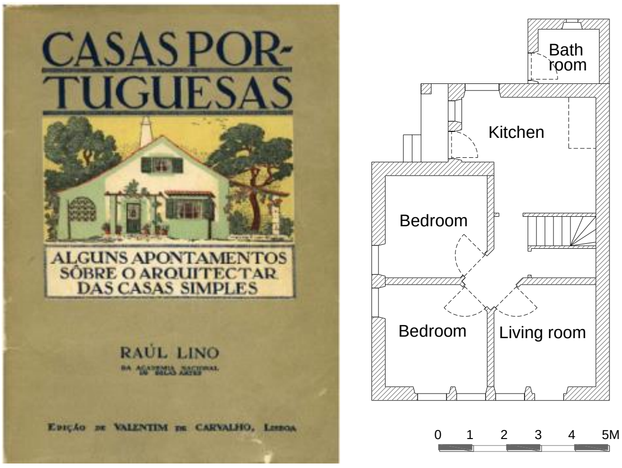


Figure 5-96 – The book of Raul Lino and proposals of technicians associated to Vista Alegre Factory and [credits plan: Alice Tavares]

Figure 5-97 – Proposals of technicians associated to Vista Alegre Factory [credits Google Earth]

However, with the end of World War II, there was a surprising return to the preponderance of old traditional models by other technicians or by VA technicians. The trial, which was open between 1940 and 1946, although with some level of control problems, would not be repeated, and the proposals arose in the 1950s following the lines of the Modern Movement with the new materials. It should also be noted that the processes of VA technical staff are now presented in association with architects from Porto, especially with Jorge Gigante (architect and engineer), and are no longer exclusively adobe constructions (Figure 5-98, Figure 5-99).

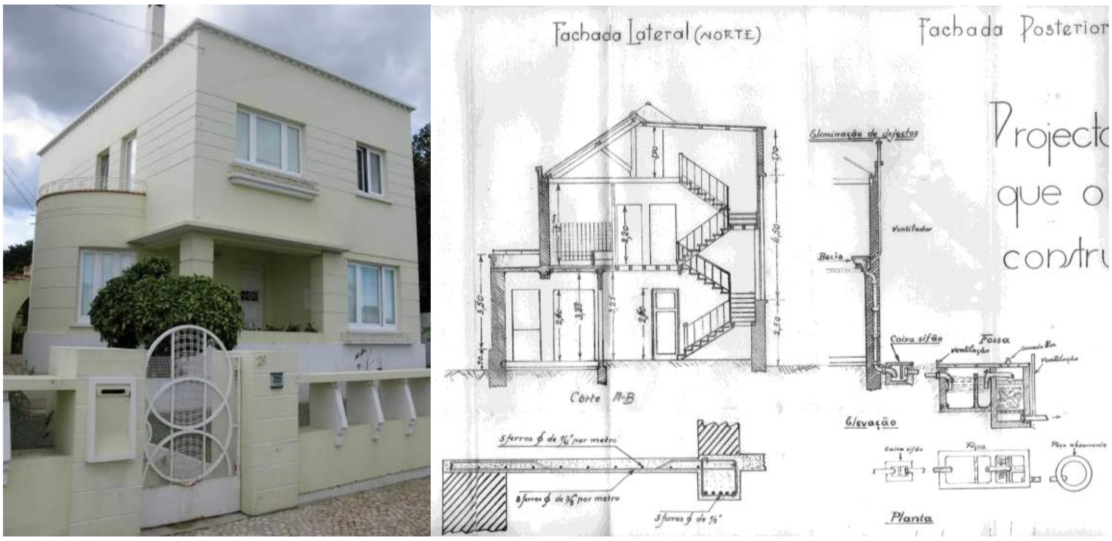


Figure 5-98 – Proposals of technicians associated to Vista Alegre Factory [credits Alice Tavares]

Figure 5-99 – Proposals of technicians associated to Vista Alegre Factory and a building of J Gigante [credits photo Alice Tavares and credits plan: Municipality of Ílhavo]

At this stage, again, also note the application of traditional internal spatial organisation but with a treatment of the façades along the lines of the Modern Movement (Figure 5-100). This aspect would come to be mimicked by other non-architects, but crudely. This reverse attitude also happened during the Art Nouveau period. VA's technicians later began to abandon the adobe architecture. This is not surprising considering their management of all the construction, alteration or extensions' interventions, including the Art Nouveau period, to the recycling of adobes and the control of its confection. It is unclear whether these also made changes to the constitution of adobe to particular areas of the building, as occurred in some instances in Ílhavo.

Figure 5-100 – Model of the end of Modernism, Ílhavo [credits Alice Tavares and M Madail]

5.3.5. Changes by the introduction of Urbanisation Plans and the actions of their authors architects in the context of Modernism in adobe (1945-1956)

The full application of urbanisation plans turned out to have a reasonable impact on construction and introduced changes. This, along with the conception of growth of cities (which in some cases was usually of 'spontaneous' form along the existing roads), the width change of the urban parcels, and the imposition of limits for construction depths (which until then could reach 20 m), are some of the novelties. Additionally, mandatory issues, under urban regulations imposed more licensing design elements to accomplish the necessary information (as a plan cut, the construction site plan), which forced the schematic presentation of its relationship with the existing building for previous approval.

Nevertheless, a decrease of information in projects designed in the 1950s, particularly in terms of covering structure solutions and constitution walls were observed. This aspect becomes questionable by the urban architects for technical projects when the span is larger than normal (over 9.0 m), and especially for industrial structures. Adobe, as a construction material, was not directly called into question, but there has been gradually greater discretion to avoid the term adobe through the mention of 'masonry from local materials'. Nevertheless, for the existing buildings, it appears that the material is still adobe in most of the cases.

A revealing aspect is the ongoing changes in construction. To understand in more detail this transition period again it was studied the case of Ílhavo, which is one of the counties that retained for a long time the application of adobe construction. One of the most interesting thigs is the impact the architects of Lisbon (authors of urbanisation plans that included the follow-up of their implementation) had in relation to the traditional technique of adobe construction and architecture.

Their urban proposals led to an alteration in the type of traditional buildings with attempts to promote multi-family construction. Proposals to open up avenues and promote zoning for urban functions, which were in vogue at the time, changed the conditions of transmission or property management but did not stop the use of adobe.

Membership in the multifamily building in Ílhavo had resistance because the social structure was based on dwellings, with autonomy of the family unit and with other complementary activities to the household economy, which could both involve the rental of small units within the lot. The backyard served as prized subsistence farming in the post-war period, which the multifamily solution did not allow.

Although not directly involving poverty because the population had a purchasing power (income) higher than the national average, single-family housing continued to be preferred, although modest. The higher density houses were those built by private families to lease with fewer resources; this model is also used sometimes to rent vacation home typologies.

However, these models fit the adobe technique, resisting the building height of reinforced concrete on the grounds that it did not allow the desired financial return at a time when iron did not arise in the market to respond to this increased search. Furthermore, everything that was in the plan that went against current practice suffered the resistance of a population that felt the new measures interfered with local interests given their strong parochial and independent sense, evident in municipality meeting documents and institutional correspondence between them and the governmental departments.

This insistence on the maintenance of ways to build was a first step towards a support base for the remaining adobe. There was a considered decision before a better understanding of the characteristics and traditions of the local population by the architects of urbanisation plans, as it was the case for action in the alleys. This was one aspect that had been identified by the architect author of the plan as a defining characteristic of the centre of Ílhavo, equating its origin as possibly ancestral settlement.

Distinct from what was known of the Porto 'islands', the position changed and accepted their maintenance given that the distances between buildings allow the ventilation of buildings. The particular attitude of these architects, Carlos O. Ramos and Samuel Quininha, throughout the process, manifests in an almost didactic way for non-architects, giving suggestions for changes / improvements of proposals, sometimes with offers of drawn sketches or designs (Figure 5-101, Figure 5-102).

Figure 5-101 – Proposal of the architect of Urban Plan [credits Google Earth]

Figure 5-102 – Proposal the architect of Urban Plan [credits Google Earth]

It must be recognised that although there was an appreciation of construction at the expense of architecture, it would be worth taking a more proactive stance with the non-architects who presented the projects to achieve a higher level of health and comfort in homes and to improve the urban image by better controlling the scale. Safety is critical when the project proponents for licensing were new graduate builders. Newcomers to the group could sign projects that were admittedly construction à la carte.

Another interesting aspect concerns the plans of urbanisation for the beaches of Costa Nova do Prado and Barra in the next period of implementation of the Plan of Ílhavo Centre. Both suffered great touristic and speculative pressure in the 1940s and 1950s. They were established in the late 19th century as resort areas suitable for sunbathing and gradually occupied the spaces left by fishermen. Nowadays, they present completely different characteristics despite their proximity and contiguity. There is still a reading of their cultural and heritage value at Costa Nova, which was only recently criticised due to demolitions in the emblematic urban front facing the lagoon. In the other beach Barra it is observed an almost complete distortion of the cultural values of the past, with a just a few positive interesting examples of the Modern Movement in reinforced concrete.

What enabled such a distinct evolution between these two areas was the differential action of the architects of the plans, their level of educational monitoring and intransigence level in safeguarding a unitary reading of the built environment. In addition, this impact had to deal with the fact that Barra was more subject to interest from investors (outside the county) and for that reason more vulnerable to irreversible changes. In opposition to Costa Nova, where the dwellings were mostly second homes rather than buildings for investment and profit, which led to a more recognition of the cultural value of the place. These are important aspects for understanding the maintenance or lack of maintenance of cultural values in the building of traditional construction systems, such as adobe or wooden construction of the fishermen.

In assessing projects, the action of the architects beyond issues of urban integration, arch centrings and clearances presents findings mainly linked to issues such as the salubrity of the buildings. Through greater concern with the requirement for natural lighting of spaces and cross-ventilation, their integration beyond the minimum areas of living spaces and promote the placement of a separation chamber for access to the toilet.

Furthermore, at this stage, through the regulation of the urban plans, there is a decrease in the height of floors used, which was usually more than 3.0 m and was changed to 2.8 m. This represented a slight decrease of construction costs signalled by these architects. Another aspect that can be concluded from the data is evident in Costa Nova Beach, where for the urban front of the coastal lagoon prevailed the adoption of aesthetic languages within the traditional architecture lines or called by the known term of 'Portuguê Suave'. The new avenue (the Bela Vista) behind this urban front suggested the adoption of more modernist language by the architect Samuel Quininha.

In addition to more regulatory aspects, the architects appreciated the aesthetic issue, sometimes proposing the project rejection based on this assessment and recommending the replacement of the technical designer. The perception that the buildings would be the heritage of the future and would condition the quality of the future urban image was the basis of many of their judgments, which were not always understood and followed. The tacit acceptance of adobe as a construction material was a positive factor for its maintenance, at least as long as the ceramic industries outside the county, including Aveiro, did not dominate the regional industrial construction market.

Another important aspect is the relationship between the proximity of these architects to the region and the knowledge and understanding of the value of traditional building techniques as a cultural value. Thus, it appears that the architect Samuel Quininha in the Plan of Costa Nova called for greater engagement with the region and presented proposals, including the use of adobe. For some buildings with a larger span between walls he also used a reinforced concrete structure. However, the fact that they are adobe solutions reveals the recognition of respect for ways to build in the region.

The architectural proposals of the urban architects that were free of charge for some owners were sometimes later repeated by other non-architects as easy to approval by the municipality and quality recognition by the society. They adapted the solutions to the size of the new urban lots and sometimes introduced slight variations. These solutions were mimicked by other technicians independently of the construction system (adobe or ceramic brick).

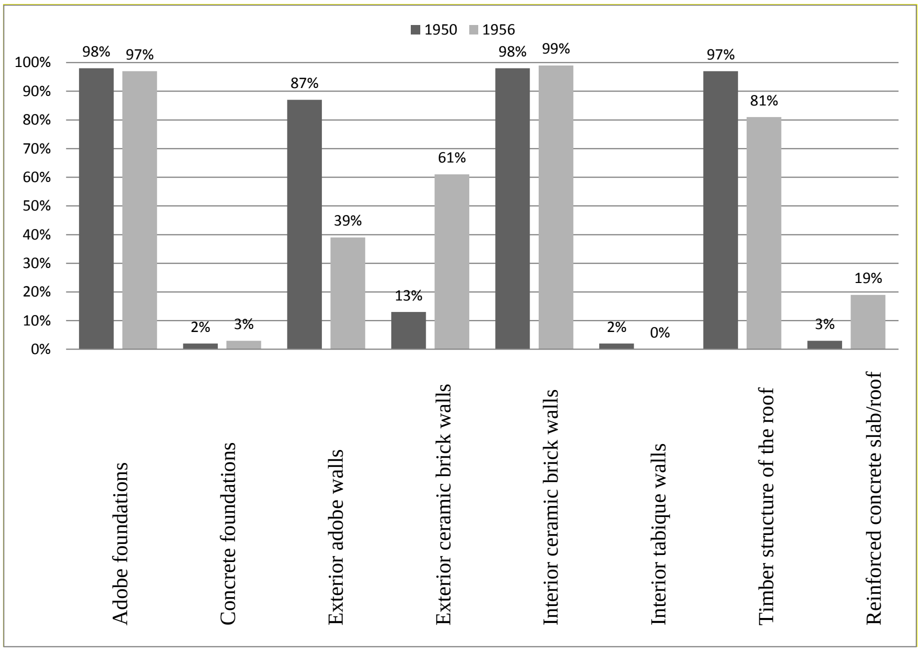
Additionally, to those who collaborated with the Factory of Vista Alegre and others, including from Porto, which also feature adobe solutions. However, they used those solutions in a mixed construction system with brick and reinforced concrete and in a more restricted use with adobe for resistant masonry.

One of the models adopted at the base has a structure similar to that used during the Art Nouveau period with the valuation of stairs to first-floor housing. What differs is that these regulations require the dwellings to face the street and to be space saving because buildings can no longer be as deep (the old buildings reached 20 m deep and now do not exceed 15 m). In many cases, the ground floor is used for storage for the house or to collect agricultural implements to be used during housing functions, usually the kitchen and the dining room and a toilet. In other cases, the sewing room is used, which, unlike the kitchen, normally occupies the space next to the main façade. The stairs are added to the main façade but with a smaller width or along the side façade.

5.3.6. The construction of the adobe system - the concerns of technicians and engineers (1940-56)

The construction system for adobe between 1940 and 1950 was perfectly stabilised. However, after 1946, the use of adobe became equivalent to the use of brick. Several authors note the 1950s as the technical disappearance period. We examine this time using two time windows with a base of 1.463 project data reporting on Ílhavo data and especially considering 1950 and 1956 (the limit of this study) with an overlapping phase of the new models and the traditional models (Table 5.2).

Table 5.2 – The construction materials used in 1950 and 1956 [credits Alice Tavares]



One of the first conclusions, already referenced, is the prevalence of adobe use in the foundations. Surprisingly, this type of foundation remains in this period even when the walls of the buildings are now brick, as proposed by the majority of technical design for this area. The foundations remain as continuous walls or external walls (60-100 cm thick during the 1940s) or interiors, but with more variable depths (referenced as having depths of 70 cm or the mention of six rows) for the outer and lower depths to support the interior walls of brick.

Adobes of 40x30x12 cm^3 are placed transversely abreast, constituting the foundation wall that is currently topped by a continuous reinforced concrete strap that encompasses the base of the interior walls of brick and satisfies all the upper surfaces of the foundation walls. It maintains the same thickness and is referenced with 2 irons Ø3 / 8 'with reinforcement at corners to above 1945 after which it was just mention the 3 irons Ø3 / 8' and stirrups Ø ¼ 'spaced 30 cm, and in 1956 and 4 irons Ø3 / 8 and stirrups Ø ¼', which are 25 cmx15 cm (bxh) in the supporting interior walls.

Usually, there is another account at the level of the door and window lintels and, in some cases, on top of another building to serve as a support for ceiling beams and / or lines of roof rafters. Continuous concrete belts unify the upper part of the walls, improving the overall behaviour of the walls. This helps to avoid the cracking problem in the corners and at the level of the highest stress areas, particularly windows, doors or gates, in addition to increasing the stiffness in the support zone of the upper timber beams.

The use of belt-reinforced concrete constructions in adobe decreases over time in terms of number and is ultimately limited to a particular foundation level, and the level of lintels ceases to be continuous and becomes only a lintel. This aspect may be related to the transition to the brick on the outside walls, mainly in the case where it is used with reduced wall thickness and 15 cm iron availability.

In 1948 the most common form of application began over concrete foundations of stone or mud. Its composition is generally referred to as *formigão* with 300 kg of cement, sand and 400 l - 800 l (litres) of gravel to a depth that was believed to be the land required. One type of foundation at an early stage keeps the outer walls of adobe.

In terms of lintels, the straps have the same 4 irons Ø3 / 8 'stirrups Ø 3/16' spaced 30-50 cm. In the case of the use of reinforced concrete pillars, their shoe stops the continuity of adobe the foundation wall. Although the system based on loadbearing masonry continues to prevail and using a scarce number of pillars (concrete or brick), the reinforced concrete portico system is still little used at this time, in opposition to the increasing use of concrete beams. In some cases, given the proximity of the coastal lagoon to the town, the concrete foundations are built on pilings. This was described as: a shoe 0.65 cm wide and 0.25 cm high is supported by wooden planking 0.65 x 0.2 x 0.03 m3 (thickness) and a base of 0.06 x 0.10 cm^2 beams with a height of 0.10 cm that connect to the 3.00 x 0.15 m^2 pine cuttings with a spacing of 0.50 m.

The exterior walls of adobe during the 1940s were referred to as being 35 to 50 cm thick. Until the mid-1940s, the main façade had a greater thickness for the remaining exterior walls, gable walls or masonry. One aspect may have been associated with the insertion of reinforced concrete elements, which were eventually 'decorative' in this façade. A decrease in thickness of the upper floors, common in the past, was also a common aspect of traditional masonry stone in northern Portugal. The thickness of these walls stabilises at 30 cm after 1945.

The adobe walls keep the percentage of use, despite the use of brick masonry for exterior walls, especially the brick three holes. The 1950 licencing processes files show the use of adobe 40 x 30 x 12 cm^3, a standard size used in this period, either for walls or for foundations (placed longitudinally) in 87% of the buildings. Astonishingly, the 1951 files, only a year later, now account for only 68% of cases.

The number of buildings with concrete blocks is quite negligible in this phase, so it was not considered in these data. However, this decrease is the apparent reality for adobe production, which maintained similar values between 1950 and 1956; that is, the number of houses built in adobe in 1950 is very similar to the number in 1956. What vary are the considerable population growth and the consequent demand for housing due to the expansion of new urban areas or agricultural settlements expansion; such was the case of Gafanha.

Unexpectedly, for a region far from the two main centres (Lisbon and Porto), the population doubled in this period. This reflects a population migration process from various regions, contrary to what was happening in other regions concerning the rural exodus for the most industrialised areas or large cities. Here, we have an increase of the rural population in the Aveiro region, the definition of new exploration areas and an increase of the working population to Santa Maria da Feira, Águeda and Aveiro. The maintenance or increase of the rural population is one of the reasons why the use of adobe kept for a longer time, including in the new urbanised areas.

The second aspect that remains stable in this period is the use of ceramic brick almost exclusively for inner masonry walls. This is placed using the shorter measure 8cm of the ceramic brick (30x15x8 cm[3]) laid with lime mortar, hydraulic lime and sand or cement and sand to the volumetric percentage (ratio) 1:4 (cement:sand).

Timber with partition walls 4.5 cm thick and plastered with lime mortar and sand and finished with a fine mass of lime and sand are becoming increasingly rare.

The mortar laying and plastering is mentioned with air lime constitution, although there has been an increasing use of hydraulic lime since the late 1940s, which became prevalent by 1956. The foundation walls have mortars with a ratio of 1: 2 (hydraulic lime:sand) applied to the exterior surface with a ratio of 1: 3; hydraulic lime in the foundations with the 1: 3 ratio and walls show a ratio of 1: 5. Depending on the provenance of technicians, after 1946, the ratio 2: 5 or 1: 4 was no longer identified in the application, even for walls or foundations.

After the end of the 1940s, the application of hydraulic lime became widespread and was applied to all kinds of walls systems, whether they were made of adobe, brick or cement block. This happened in a reaction by technicians to what was a very comprehensive problem, moisture effects, especially rising damp. However they did not mention other causes, some arising from the design of the proposal and others due to changes introduced in the traditional system of construction or by the introduction of new materials.

In relation to the structure of the floors there were almost no variations in this period. These structures were mainly of pine beams with 50 cm spacing. The different cross sections in use are linked with the timber market. It could be from the interior region of Aveiro or from the north (Porto region) following standard practice since the 19th century marketing of construction products through the port of Aveiro.

The predominant beam section is 18x9 cm^2, although there are cases of 20x10 cm^2 with a spacing of 40-45 cm (the section most used in the 19th and early 20th centuries), 18 x 8 cm^2, and 18 x 10 cm^2 maintaining a spacing of 50 cm. Some variations are attached to the beam, although the data show in many cases even with larger openings in the same section a range from 7 m. The timber floor boards that were rigged and 28 mm thick in 1950 were 26 mm thick in 1956.

The kitchens and bathrooms have slabs of reinforced concrete, the so-called 'reinforced brick plates' with hollow bricks 30 x 15 x 6 cm^3, arranged in parallel rows so that the intermediate ribs receive the steel bars provided in the calculation. The bricks were covered with a concrete compression blade 3-4 cm thick, leaving the plate with a total thickness of 10 cm. The constitution of the concrete was often of 300 kg cement and 400 l and 800 l (litre) of sand gravel.

The slabs were found on the walls, in many cases under the total thickness of adobe walls and sometimes noticeable from outside. At the ground-level, wooden floors were usually replaced by a reinforced concrete slab with a ratio (volumetric percentage) of 1:3:4 (cement:sand:gravel), with gravel 10 cm thick on which rested the flooring. In other cases it is referenced a foundation based on hydraulic screed with compacted shards (1948).

The overlay solutions at this stage continue with a very significant use of pine wood structure almost exclusively until 1950, and in 1956, reinforced concrete slabs are present in almost 1/5 of the cases.

Finally, the collection of data on technicians responsible for the submission of licensing process shows that in the first phase (1940- 1949), the technicians who already worked in the region, with experience in the application of adobe construction as well as proximity to the habits of the people, maintained the traditional techniques.

However, it appears that in the late 1940'sand especially in the early 1950s a second generation of technicians emerged. They were the recently graduated technicians from regional technical schools. Contrary to the previous generation, they dramatically decreased the use of adobe for loadbearing walls, probably due to their training better adapted to the widespread new construction with reinforced concrete. This is an interesting finding given that the loss of the use of adobe is justified by the training of technicians besides the introduction of concrete, a factor to be considered. However, in this region, the training of technicians and the growing weight of ceramic industries (brick) were the main causes for the abandonment of the construction of the adobe construction system.

5.3.7. Prevention of defects and material compatibility identified by technicians

It should be highlighted the main concerns of the technicians of the 1940-1956, present in their written documents used for the licencing processes. Some of them are set out nowadays in seismic regulations for adobe construction in countries such as Peru, New Zealand and Turkey. References to the use of reinforced concrete ring beams above foundation walls were regarded as fulfilling two functions. The first was a way to prevent uplift humidities, sometimes with the concomitant application of crude oil substitute in the transition zone between the foundation wall and the wall or under the belt of reinforced concrete or under the floor of the framework. It established itself as a water cutting system and was applied in the foundation walls to a height of 20 cm to 80 cm above the outer part of the ground, despite being no longer applied generally in the 1950s'.

The other function refers to the continuous characteristic of concrete belts at the foundation level covering the entire lattice of the base of the walls, indoor and outdoor. This allowed a more uniform distribution of loads by foundation walls, avoiding any areas of greater weakness in the openings of the foundation walls for ventilation as well as the worst effects due to possible settlements of the ground. Focussing attention on concrete belts verified that these were the basis for supporting the wooden structures (floor or roof) or in addition the area function for the lintels of the inner brick walls. This is one of the aspects mentioned in the 1945 processes and was a breakthrough for the cohesion of the system, which had not happened in many cases in previous periods. In situ hits found that these buildings used metal tie rods to join opposite walls of the façades. In addition, steel beams were normally embedded in the upper part of the longitudinal wall, but this strategy is no longer observed in the buildings mentioned in this period.

Another preventive measure used, especially in the mid-1940s, was the inclusion of ventilation windows on opposite walls of the façade in addition to other ventilation windows in the interior foundation walls allowing the free movement of air. This concern already present in previous periods, as noted in Chapter 3, it was to allow the reduction of moisture levels in the base construction. Again, this was to allow the maintenance of dry wood in construction and to avoid the occurrence of rising damp. The problem of moisture underpins the growing use of hydraulic lime (from 1945) and earth mortars for exterior walls or cement mortars for interior walls (of brick masonry).

At this time, the reference appears to use diatomite mortars (mortars with diatomaceous earth) for exterior rendering and in the transition area between the foundation wall and the adobe exterior wall. Additionally, it was used the same mixed mortar to accomplish the waterproofing the transition zone to the ground / pavement outside. Diatomite is composed of silica and fossilised remains of diatoms and has many applications in industry for filtering aggregates, such as thermal and sound insulation qualities as fillers. The cell structure makes this a poor conductor material, except that it can absorb 1.5 to 4 times its weight in water and does not increase significantly in volume (Construction Materials, 1991, p330).

Its similar characteristics to the pozzolan (Report 37 RILEM, 2007) according to laboratory results developed by Rosario Veiga, at LNEC, increase strength, providing greater durability to mortars and compatibility for rehabilitation interventions.

This use of diatomite was mainly proposed by northern civil engineers (mostly from Porto), especially with a ratio of 1:3 (cement and sand), to which was added 5% of diatomite. This addition was sometimes referred to as aiming for complementarity of waterproofing. However, in addition to cement mortars, lime mortars (*cal aerea*, in marked decrease after 1945) and hydraulic lime were applied.

5.3.8. The introduction of errors in the adobe construction system after 1940

In general, all adobe construction elements have lost sections over time, either the wall thickness or the cross section of the wooden beams of the floors, or the roof structure. This is symptomatic of changing the dimensions of adobe, shown by the thinnest use of adobe in the 1950s at 25 cm and 20 cm (40 x 20 x 12 cm^3). This aspect will lead to the diminishing of its bearing capacity and thermal inertia, compromising one of the characteristic features and added value of the material.

The use of adobe walls with less quality (usually just used in exterior walls' divisions' of lots) in dwellings was a first setback to the maintenance of this traditional technique in the 1950s. The laboratory tests generally have a lower load capacity than others (Varum H et al., 2006). The high demand for housing, above what the traditional construction market could offer, could justify this, as well as the lower structural safety, durability or comfort, associated with these changes.

The continuity of these solutions during the 1960s contributed strongly to the decline in confidence in the traditional system and its increased use just for secondary buildings. Another aspect to be mentioned was the decrease of the depth of the foundations in many cases; the foundation can be very shallow, less than 0.50 m in adobe. This can be a reason of less stability of the construction, more subjected to not surpassing changes in the silt soil base.

In addition to the reduction of structural quality, it is important to mention a decrease of the conditions of durability and material compatibility. On the one hand, sanitary base ventilation space was disappearing, raising the problem of moisture uplift in an area where the water level is usually high due to the proximity of the coastal lagoon. On the other hand, there is the problem of the simple use of concrete slabs as a waterproofing measure, which does not work because it depends on the compactness of the concrete level, the mixture constitution.

The use of cement in joint mortar in the adobe foundations (after World War II) is another factor in the introduction of construction defects, particularly given the type of soils with a high water table. The chemical incompatibility and mechanical issues between the adobe and cement are damage causes commonly observed involving incorrect repair interventions.

At this time, the loss criterion for cement use, which was first used for only interior brick walls and therefore compatible with ceramic brick, came to be used interchangeably or in adobe or ceramic brick masonry.

This decrease in building quality began to be apparent in the late 1940s and is symptomatic of solutions in the transition to brick masonry with replacement by a simple adobe brick wall with 15 cm thick masonry or two panels of brick cutlass 30 x 15 x 8 cm^3. That is, this was a period with a high percentage of construction problems in buildings regardless of the material of the walls.

5.3.9. Final comments

The adobe buildings built in the 1940-1956 period reveal two distinct phases in Aveiro, where an experimental phase of organisational and aesthetic types was implemented by civil engineers, architects and some non-architects (mainly linked to the Porcelain Factory of Vista Alegre). This experimentation includes references produced for the workers' neighbourhood Vista Alegre but goes far beyond this model, creating models that are easily distinguished from the others and, in some cases, will be repeated by other technicians of the region.

The company had its own body of engineers and other technicians who were responsible for the new construction, maintenance and rehabilitation of buildings, a process that used the recycling of building materials and control quality of the intervention, thus ensuring the experience to know the potential of adobe and the aspects to control for its preservation. Furthermore, the connection facilitated by architectural services in Lisbon and in Porto can be the basis for some solutions; it was common to send pencil sketches of projects by architects, which were then adapted to the constructive adobe system, as well as the functions required and the compatibility with existing conditions.

These professionals broadly maintained the adobe technique, both for buildings in Vista Alegre and in the county and with a connection to the owners with greater economic capacity, such as industrial fishers, captains of the merchant marine, medical professionals and wealthy farmers. However, this was not exclusively the case because their actions were developed, especially in areas where they had land and buildings, but also in areas where the workers lived or in the vicinity of the VA neighbourhood, in the connection area to the port of Aveiro and fishing zones. These technicians were those who promoted, before the entry of the architects, an approach to new living space conception, outside the traditional system.

The fact that the areas of expansion in Ílhavo have mainly been associated with agriculture that does not require special design conditions and is a more conservative activity favoured the continuation of adobe use. This is one of the important reasons for maintaining adobe, the application of which decreases in the central urban areas but grows in the areas of new urban development. In addition, it is one of the reasons for the fact that after World War II, there was a return to the traditional types, significantly reducing the buildings of the Modernist trial period. There was a return to the roots in the buildings of adobe following the Modern Movement with brick, although the adobe foundations were the last adobe element to be removed from the building system.

Regarding the decline in the use of adobe, rather than the cause of the increasing use of reinforced concrete in this region, the issue was the pressure of the ceramic industries, changes at the training level and knowledge about traditional construction technique of technicians and engineers. In addition to regulatory changes, particularly after the implementation of the Development Plans, it was observed a gradual disappearance of the technique.

The adobe building heritage has found expression in various regions of the world and is very rich in terms of cultural diversity, revealing a deep connection to the social and natural environment. This study addressed its final implementation stage in Portugal, particularly the period connected to World War II, an interesting and multifaceted phase in which the dialogue between vernacular architecture and classical architecture reveals many thoughts, questions and debates that characterised the time, including architects, technicians and society in general.

5.4. Retrofit of thermal behaviour of adobe buildings versus challenges to maintain authenticity

5.4.1. Introduction

This subchapter is structured as follows. First, a description of the methodology of the approach composed of four steps is presented. Second, the characterization of the construction systems, involving traditional techniques as well as the industrialised solutions (1940-1959); is discussed. Third, the process of two years of thermal monitoring in situ is described. Fourth, the work conducted to model the main typological construction solutions identified is presented (1940-1959). Fifth, the results are discussed. Finally, the main conclusions and remarks on this research are presented.

5.4.2. Thermal retrofit needs and compatibility with the protection of authenticity and integrity of the ancient buildings

The research presented in the previous chapters sub raises the question of compatibility between regulatory requirements and maintaining the authenticity and integrity of the built heritage. This is the most patent right at the approach of minimum and maximum levels of comfort rate proposed for the region. As these high and considered by this author as inadequate for the old buildings, for three main reasons:

- to accomplish such high thermal comfort standards it will be need a great amount of energy consumption or a highly intrusively intervention, which is unfortunately carried out in Portugal with the support of governmental programmes for the changes of the old timber frame windows and doors, beside other type of interventions. This is presently one of the most important causes of loss of the cultural value of vernacular heritage and built heritage in general;

- the increase of the interior temperature established in the regulations will affect the balance of humidity inside the buildings and with this affect the materials imposing mechanical changes, namely in the timber elements (ex: structure of the floors and roofs), sometimes with the retraction of the material and presence of cracks. On the other hand, this is only possible through the hermetic closeness nowadays applied to the new construction for the windows and doors. This impose also a negative aspect due to the fact that this ancient type of construction need an air exchange for the “breath” of materials, as in relation to the adobe walls as in relation to the timber structure.

- the usual solutions adopted nowadays by the technicians, explaining that they are following the thermal legislation assume also as good solutions the thermal retrofit of walls in its exterior face. In the most part of the cases this is not possible to apply to ancient buildings without a huge damage in the image of the building and loss of cultural value. For this reason it should not be applied without a previous evaluation of the impact involving this aspect.

The research and guidelines of the English Heritage (EH, 2014) present a very interesting approach in this matter. Considering that the cultural value of a building represent sometimes hundred years of history and a legacy to protect, it has been developed studies to evaluate the loss of energy of the ancient fabric and which available possibilities that can be applied without almost any change in the facades and in the roof configuration. It is assumed that if there is not in the present solutions that can accomplish the high standards of thermal comfort it is because it is needed more research about this matter. This assertive position that assume that the lack of response to complete those standards do not allow anyone to damage the authenticity and integrity of the building based in a lack of research. Nevertheless, they propose several measures to the owners, guidelines for the intervention criteria following a national conservation philosophy that protect more effectively the built heritage. The different levels of approach, from the easiest measures of take the best advantages of what already exists in the buildings as shutters until the proposal of application of a second glazed window or the retrofit of thermal insulation of the roof without change its configuration or the addition of solar panels (despite its use is not allowed in certain cases of historic urban centres). It is a work in progress that needs a more deeply research to achieve better solutions capable to assume the challenge of protection of the built heritage.

5.4.3. Criteria contradiction in research and practice of thermal retrofitting adobe buildings

5.4.3.1. Reflexion about the thermal behaviour of adobe buildings (1940-1959)

Currently, a significant number of adobe buildings belong to the period after 1940. These buildings are the last witnesses of the adobe construction in the Aveiro district. Thus, they have significance in terms of the history of construction and in terms of the last use of vernacular architectural models in an increasingly engineered time. This study focuses especially on the period from 1940 to 1959 because it is the most relevant transition period of changes in the construction system. From previous studies that identified several solutions to wall materials, we have chosen the main types. The objective was to evaluate the thermal characteristics of each solution, not only because this can provide information for thermal retrofitting but also because it allows the comparison of those solutions. The importance of this information has two other concerns for research: first, the information is necessary to know the level of retrofitting that those buildings need to adopt less intrusive measures; second, to produce historical knowledge about the gains obtained with the change of materials, including the level of thermal improvement with the substitution of adobe for brick masonry. This was a period of decreasing thickness of adobe walls; for this reason, the recognized thermal behaviour could be compromised.

Furthermore, this period is very relevant in terms of architecture due to the increased adoption of Modernist architectural design.

Recent interest in retrofitting Modern Movement buildings is growing and is an acknowledged issue in recent reports of ICOMOS, noting the risk of losing this heritage. Some reports state that the heritage of the last fifty years encourages particular research due to increasing redevelopment pressure based on material conservation problems. The identified major threats faced by 20th-century heritage include legislative pressure for the application of building codes. One issue that is under great national debate is the thermal regulation topic due to the imposition of massive changes to the ancient fabric with the justification of improving energy efficiency. However, the absence of pre-assessment criteria for interventions that can also accomplish balanced measures to maintain the authenticity of the buildings is a main threat to this heritage. There is a contradiction between the rehabilitation of the building and the idea of increased value; instead, there are irreversible changes to the authenticity and consequently to the cultural value. This globalized idea gives all buildings the same treatment by imposing uniformity independently of the characteristics of the building. On this subject, this study considers significant for the debate the guidelines of English heritage and the research of the Portuguese architect Nuno Valentim (Valentim N 2006) in relation to criteria to maintain the original timber windows and doors. Although those studies are mostly related to stone buildings, the main issue of debate is the same as for adobe buildings, which is how to balance thermal retrofitting without losing the authenticity of the building.

In relation to this research, considering the debate about adobe buildings, a work-team was developed with Mendes C (2015) under the supervision of Romeu Vicente and Aníbal Costa at University of Aveiro. To achieve better conclusions for the preliminary identified issues, Mendes developed a dynamic building simulation using the program EnergyPlus, which gave unexpected conclusions. Although this type of approach needs to be further developed with other case studies for comparison, this was an interesting point in relation to the buildings of this region. Another important complement of the study was the thermal in situ assessment over two years in some of the case study buildings of the author (Mendes C et. al 2015). This study allows wider understanding of the behaviour of these buildings. The data obtained will be in development in the following months.

The study of thermal performance analysis was conducted in residential buildings from the central region of Portugal. In this region, a wide range of solutions of the 1930s present links to traditional construction systems and the later solutions of the 1950s and the widespread use of reinforced concrete. Additionally, the position of the architects and stakeholders in relation to the social effects of World War II implied increasing concern about housing conditions, namely ventilation, sunlight exposure and minimal dimensions of indoor compartments, introducing the correlation of those topics. One of the most notable qualities of earthen buildings is the good thermal inertia. This is one of the reasons why this type of building was used until at least 1971. This is an impressive heritage to recover and protect for new buildings in Portugal and in many other countries. The sustainable criteria related to the management of resources, diminishing energy consumption and diminishing CO^2 emissions are a focus of studies about earthen construction. In particular, its thermal properties, the improvement of energy efficiency and underlined cultural values are in focus in relation to the existing buildings and the need to rehabilitate them. Although some research has been developed about the thermal behaviour of earthen construction, a lack of information has been identified involving the comparison of the thermal behaviour of the systems of construction solutions of this transition period (Figure 5-103).

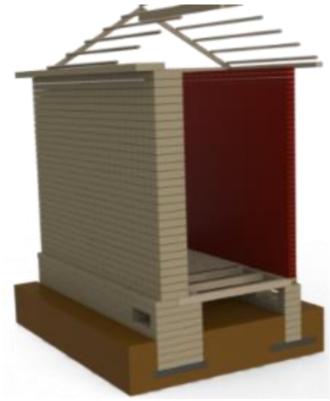


Figure 5-103 - Traditional adobe Construction system and photo of adobe masonry [credits Alice Tavares]

The adobe construction system of the case study has loadbearing adobe walls complemented with timber structures for the floors and roof, a traditional technique present in many countries worldwide. It is important to characterise the thermal behaviour and identify the need to improve energy performance for the promotion of the occupation of those buildings that are, in many cases, uninhabited. The knowledge required for the technical community to see the kind of adjustments or reinforcement techniques is needed to increase comfort with less energy consumption. However, this study also attempts to compare adobe solutions with their contemporary loadbearing brick masonry with reinforced concrete and to determine whether these solutions that have progressively replaced adobe constructions were indeed better. Currently, due to unjustified prejudgements. earthen buildings are being demolished due to a lack of information at the level of decision makers.

5.4.3.2. Methodology of approach

The methodology used to analyse the thermal performance of the identified construction systems was based on a four-level approach. First, we consulted the data from the Municipality Archives of Aveiro and Ílhavo (two cities with relevant adobe heritages) and architectural design plans, from which we identified and selected representative typologies. The other level of the work concerned the in situ surveys, a relevant part of the work allowing the validation of the use of the technique identified in the design project plans.

The methodology used to analyse the thermal insulation performance of the adobe buildings was based on in situ work to collect information on the thermal-hygrometric conditions of the buildings. The data were collected over two years starting in June 2012 to ensure monitoring of the four seasons. The recommended equipment to process this specific work was composed of ambient temperature sensors with a data logger with the capacity to record and store data to support the validation of a thermal dynamic simulation using EnergyPlus software.

5.4.3.3. Characterization of the construction systems between 1940 and 1959

The period between 1940 and 1959 was chosen because it was identified in previous work as a transition period for construction systems and for architecture. The main difference occurred in the walls and not so much in the structure of the floors, where the timber structure was mostly maintained with exceptions for the spaces of kitchens or bathrooms located on the first floor.

The same occurs with the roof structures in terms of the maintenance of their timber structure despite differences in their design/conception. The ventilation base below the timber structure on the ground floor should be maintained despite the variation in height. A lower ground floor continues to be used mostly for secondary functions but not for the living use of owners.

In relation to adobe buildings, the construction system was stabilized in two typologies and in relation to the brick masonry, with some elements such as reinforced concrete slabs, pillars and beams present in the three main construction typologies for external walls. Table 1 shows the different wall typologies selected for the study (Table 5.3).

Solution A: adobe of 0.40x0.30x0.12 m (length x width x height) – single leaf walls are rendered by 0.025 m of plastering on both sides of the wall, completing 0.35 m of the total finished width of the wall.

Solution B: ceramic bricks - the single leaf walls are rendered by 0.015 m width of plastering on both sides of the wall, completing 0.33 m of the total width of the wall.

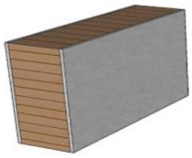
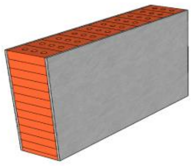
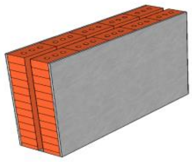
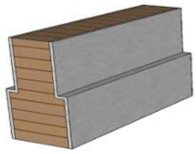
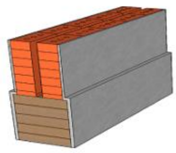
Solution C: ceramic brick (with three vertical holes) - the double leaf walls are rendered by 0.015 m width of plastering on both sides of the wall. The intermediate air space was in many cases from 0.05 m (adopted for this study) to 0.12 m, completing 0.38 m of the total width of the wall.

Solution D – The main difference between this solution (the traditional type of adobe construction in the region) and Solution A is the dimension of the adobe blocks and their position in the wall fabric of the ground floor in relation to the upper floors. This solution included adobes of 0.45x0.30x0.12 m (length x width x height)- the walls of the ground floor were a single plane, with adobes in transversal position, and they were covered by 0.025 m width of plastering on both sides of the wall, completing 0.50 m of the total width of the wall at this level. On the upper floors of the adobes, the walls were a single plane covered by 0.025 m width of plastering on both sides, completing 0.35 m of the total width of the wall.

Solution E – This is a mixed construction solution with adobe applied at the ground floor and ceramic bricks used for the upper floors. At the ground floor, the adobes were 0.40x0.30x0.12 m applied transversely in a single leaf rendered by a 0.025 m width of plastering on both sides of the wall, completing 0.45 m of the total width of the wall. On the upper floor, the wall was built using ceramic bricks (with three vertical holes). The walls were a double leaf rendered by 0.015 m width of plastering on both sides of the wall set. The intermediate air space was in many situations 0.05 m, completing 0.38 m of the total width of the wall (0.015+0.15+0.05+0.15+0.015 m).

Solution A represents the majority of the building solutions (it substituted for the previously traditional type D at the time) and it was applied mainly after the 1930s. This reveals that the traditional type of construction continued for longer than expected in a region that had several ceramic brick factories at the time. Nevertheless, the interior walls were mostly brick masonry in all of the solutions of this period, although some of them used adobe or tabique, but rarely. The bricks used in the interior walls were usually the same as were applied to the exterior walls but with a different position, constituting a total width of 0.11 m (0.015+0.08+0.015 m).

Table 5.3 – Five external envelope solutions – thermal transmission coefficient [credits Carlota Mendes]

External Wall Solution		**Thermal transmission coefficient - U ($W/m^2.^oC$)**	
Solution A		2.06	
Solution B		1.56	
Solution C		1.15	
Solution D		Groundfloor	1.61
		1st Floor	2.06
Solution E		Groundfloor	2.06
		1st Floor	1.15

Currently, there are still many buildings displaying Solutions B and C, although neither is very representative of the period (1940-1959). These solutions began to be applied during this period and were the most commonly adopted after. Solution D represents an ancient adobe solution that was more common before the 1930s, until it was substituted by Solution A. Solution E corresponds to fewer new buildings at the time, but it represents a majority of the existing buildings that have been subjected to the addition of upper floors. This solution was adopted in its original form during this period.

The earthy rendering of the exterior walls, which includes lime, was a layer of 0.025 m thickness for adobe walls; a mixed system and cement mortar (thickness of 0.015 m) were used for the ceramic brick masonry.

The greater part of the construction systems adopted maintained timber beams, regularly spaced, with total height of 0.21 m including their recovering with timber slabs. The reinforced concrete slabs (with ceramic bricks) built during this period was usually 0.14 m in width (0.10 m slab + 0.04 m recovering) and was used in just a few spaces (kitchens and bathrooms). Only in the 1950s were entire slabs adopted more extensively; the same happened with double brick walls and reinforced concrete solutions incorporating pillars and beams. The roof structures were mostly timber structures, generally king post trusses, but a few had reinforced concrete slabs.

It is currently assumed that in these adobe buildings, the finishing of exterior walls consisted of whitewash painting. Nevertheless, this research also concludes that many other colours were adopted, particularly in Ílhavo; in many cases, these colours were associated with maritime activities and the colour of the ships. The owners liked to show their pride in their connection with a particular ship by painting the house with some of the ship’s colours. For this reason, we find in the interior layers of paint or in old photos that darker colours such as dusky pink, anthracite blue or bluish green were being used. The use of different darker colours can affect the results of the thermal modelling study and have a positive effect on heating. This is a relevant issue when evaluating the impact of energy consumption during the winter period.

In Portugal, adobe construction was used for different types of functions, but a higher percentage of dwellings with one or two floors exist, followed by warehouses or small factories.

The evolution of the adobe construction system shows that in this region, the thickness of the exterior adobe walls had been decreasing since the beginning of the 20thcentury. The solutions currently presented have almost half the thickness of the common walls used in ancient times. The good thermal quality of adobe walls is currently recognized by many researchers. However, observing this decrease in width, the question arises as to whether it affected this particular positive characteristic of thermal behaviour. Could these thinner walls be a disadvantage in relation to brick solutions and compromise the continuity of their use? Could this be a reason for the progressive disappearance of this old technique?

In fact, the data collected show a decrease in the percentage of adobe buildings. In the period between 1945-1949 88.7% of construction was adobe, 10.2% was brick masonry and 1.1% was other materials (stone and cement blocks). Between 1955-1959, the percentage of adobe buildings dropped to 60%, brick masonry was 39.4% and 0.6% was other materials. In fact, the use of the traditional adobe technique did not diminish as quickly as is usually assumed. Again, this situation raises another question as to whether the decreasing thickness of the adobe walls maintained sufficient thermal capacity that could compete with the new brick solutions adopted afterwards.

5.4.3.4. Two years of thermal assessment *in situ* and during the data collection period

Over the last two years, this research has monitored five dwellings, all in Ílhavo and Aveiro, to collect data about their thermal behaviour and humidity during the different seasons. The buildings are all from the 19th century until the 1940s. The measurement device is composed of various temperature and relative humidity sensors. To fully monitor the dwellings, the sensors are located with one on each floor, including the attic, and one outside in a place where it is not subject to direct sunlight or rainwater. The interior and exterior temperatures (Ti (n) and Te (n)) were measured using thermo hygrometric equipment kept indoors and outdoors. The temperatures and levels of humidity were measured continuously, despite some setbacks with the operation of some devices, namely, those applied to the exterior, including a higher number of solicitations and therefore faster pile consumption as well as exterior devices that were dropped during winter storms. Nevertheless, these setbacks did not present a substantial problem because we also continuously obtained this type of data from the Department of Physics at the University of Aveiro. Nevertheless, these issues justified the study continuing beyond one year to collect all of the necessary information.

The owners' routines were known in terms of their use of heating devices or fireplaces and of opening doors or windows for ventilation during the year. These were recorded, except for the holiday periods (from one week to a month), when these houses were closed.

The results from the in situ thermal assessment are one of the goals of this research work, which focused on assessing the thermal behaviour of buildings from this transition period. This information may be helpful for future programs that support the thermal rehabilitation processes of adobe construction, similar processes such as rammed earth, or even buildings from the Modern Movement architecture or their contemporaries.

5.4.3.5. Modelling typological constructions solutions (1940-1950)

For the modelling carried out by Mendes (Mendes C et al. 2015), the most representative of the old dwellings was selected. This typology was continuously adopted until the 1950s, with just slight differences in the position of the front porch, the thickness of walls and the compartment height of the interior spaces.

The dynamic building simulation used the EnergyPlus program. The thermal performance analysis is based on the national thermal code REH (DL nº118/2013) and the European standard EN 15251 (CEN, 2007-08).

5.4.3.6. Characterization of the building used on the dynamic building simulation

The adobe building chosen for this section of the work was built at the end of the 19th-century and belonged to a navy captain and ship owner. It is located at the city centre of Ílhavo (Aveiro district in Central region of Portugal) on a main street that connects many other municipalities. The building has a regular shape and three floors: a low ground floor, a first floor as the primary living space and an attic partially used as living space (Figure 5-104).

Figure 5-104 - Location of the dwelling monitored [credits :Google Earth]

This construction is an ancient traditional type (Figure 5-105, Figure 5-106), with exterior walls of adobe masonry, interior timber-framed walls with an earth render known in

Portugal as tabique, and a timber structure for the floors and the roof. On the roof, there is thermal insulation 5 cm thick. The render of the walls is made of an earthen mortar with lime, while the roof used ceramic tiling (a plane type called telha Marselha). All of the openings are timber framed with a simple glass plane 3-4 millimetres thick. The front façade is oriented towards the southeast.

The town of Ílhavo is located in the winter climate zone I1 and the summer climate zone V2, expressed at the Portuguese regulation of REH (DL n.º118/2013) (Mendes C., 2015). The heating season includes 6.3 months (from the 1st October until the 9th of April, a total of 4584 hours) (Mendes C., 2015). The building is surrounding by some vegetation, namely, some trees at the northeast elevation along the front wall.

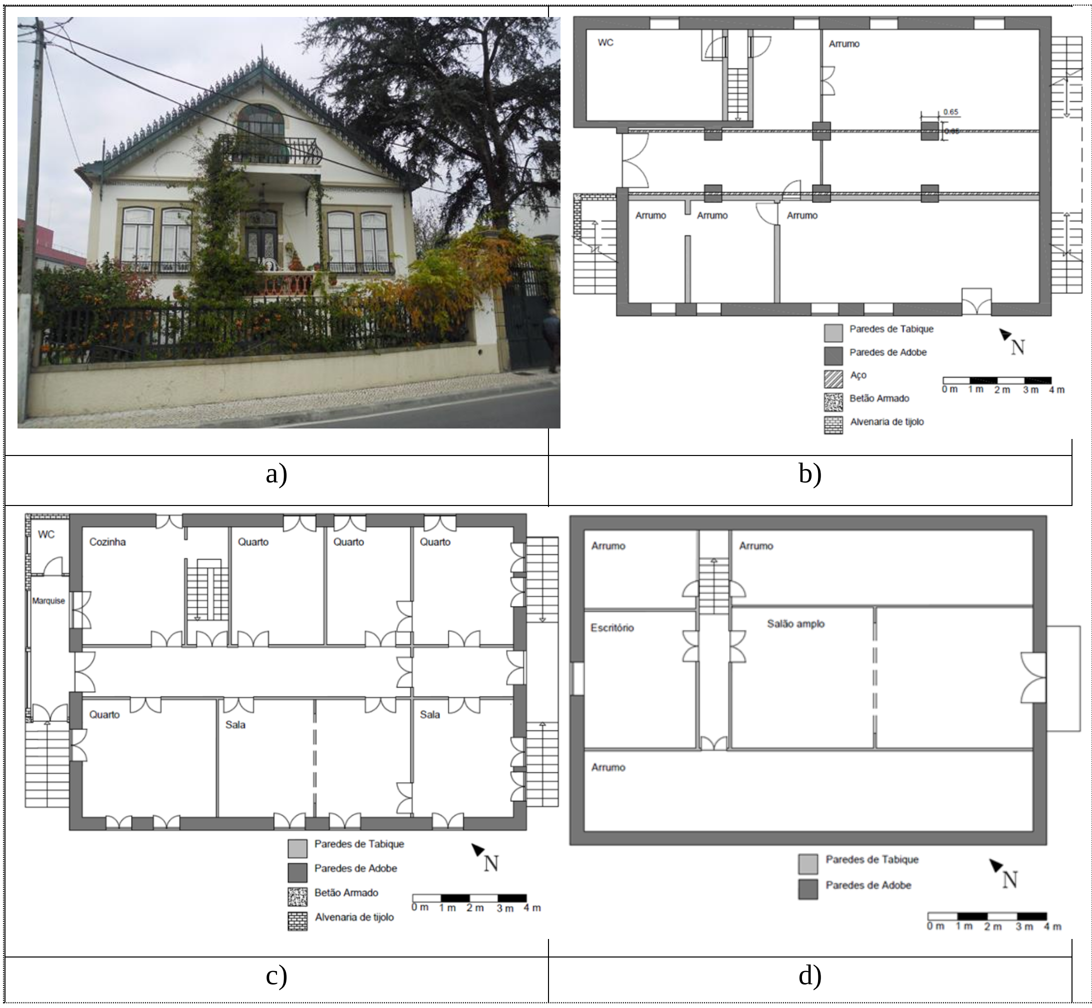


Figure 5-105 – Configuration of case-study building. a) Principal facade; b) Groundfloor plan; c) First level plan; d) Attic plan [credits. Diana Cancela].

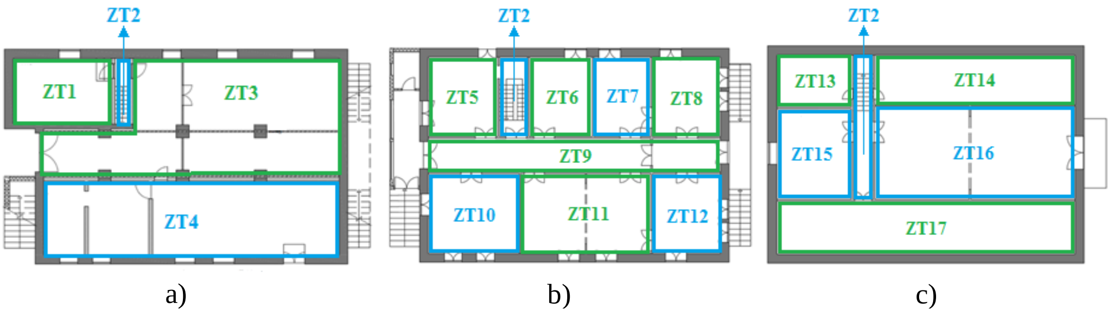


Figure 5-106 – Identification of the thermal zones. a) Groundfloor plan; b) First floor plan; c) Attic plan [credits Mendes C., 2015]

5.4.3.7. Reflexion on the data from numerical modelling of the 19th century building

For the modelling, the most representative of the old dwellings was chosen (Figure 5-107). This typology was continuously adopted until the 1950s, with just slight differences in the position of the front balcony, the thickness of walls and the height of the interior spaces. The dynamic building simulation used the program EnergyPlus for the data collected in situ.

This study only considered the building in its original shape; for this reason, posterior alterations were not included, namely, the closed balcony or the bathroom, which were both on the first floor towards the backyard.

As the first step in the construction of the modelling, a model geometry of the building was created and thermal zones were defined. The thermal zones coincide with the partitioning of the building, except for two on the ground floor that are composed of several rooms that present similar characteristics in terms of use scenarios, lighting, equipment, ventilation and climate systems as well as construction characteristics.

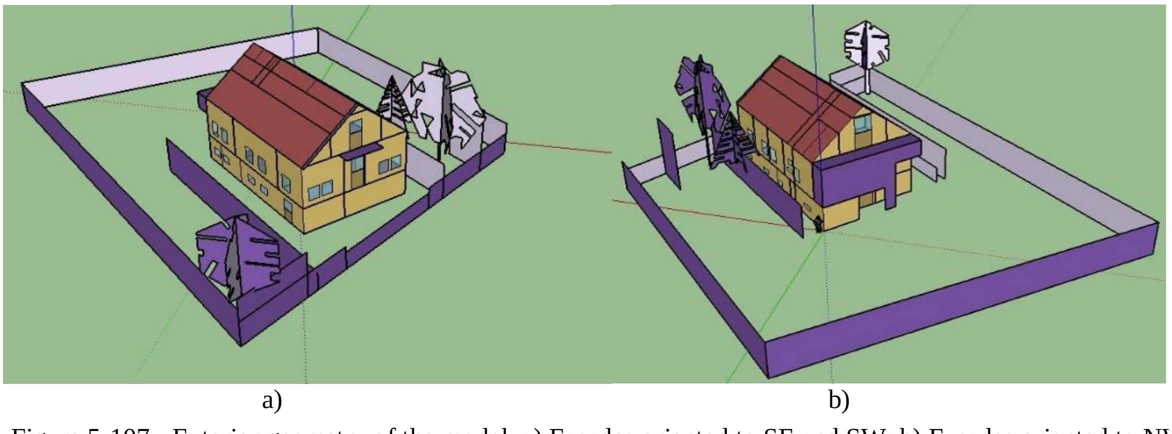


Figure 5-107 - Exterior geometry of the model. a) Facades oriented to SE and SW; b) Facades oriented to NW and NE [credits: Mendes C 2015]

To introduce the materials, in addition to the thickness, the program requires the following tabled values: thermal conductivity, density and specific heat. These values, the material's thickness and the thermal transmission coefficient are presented in Table 5.4. With this information, it was possible to characterise the building's construction solutions. (Mendes C 2015).

Table 5.4 - Properties of constructive materials [credits Mendes C]

Elemento construtivo	Material	ρ (kg/m^3)	λ (W/mºC)	C_p (J/kgºC)	Thickness (m)	Thermal transmission coefficient (W/m^2 ºC)
Exterior walls	Adobe	1880	1.1	880	0.41	1.71
	Plaster	1600	0.8	880	0.025	
Interior partition walls	White painting	1880	1.1	880	0.002	1.59
	Earth (silty sand)	1880	1.1	880	0.04	
	Timber	750	0.23	1758	0.05	
Interior timber wall plates	Timber	870	0.29	1758	0.03	1.74
Roof	Timber	870	0.29	1758	0.026	0.63
	XPS	33	0.037	1470	0.05	
	Ceramic tiles	1500	0.6	800	0.01	
Groundfloor	Earth slab	1500	1.5	880	0.3	-
	Floor screed	1600	1.15	840	0.06	
	Ceramic tile floors	2000	0.9	920	0.015	
Floor with wood covering	Timber floor	750	0.23	1758	0.025	1.05
	Timber joists	750	0.23	1758	0.23	
	Wooden plaking	750	0.23	1758	0.015	

In relation to internal heat gains (heat produced by equipment, lighting and human occupation) it was considered that its representative value is half of the average internal gain value indicated by REH (DL nº118/2013), because the building only have two inhabitants. So, the value is 2W/m2, for both seasons (Mendes C 2015).

The building under consideration has no air conditioning equipment, operating with free float; however, as a heating medium, it contains a fireplace in thermal zone ZT11 that works during the period from November 1 to March 7.

In the present case study, the building does not have any ventilation device. Natural ventilation occurs through window openings, doors and roof attics.

Data about furniture were also included as internal mass in all thermal habitable zones.

For shading devices, following the indications of the owner, the building has wooden shutters on the first floor painted white that are only used during the summer period, with the exception of two thermal zones oriented towards the SW. The rest of the year, the window shutters always remain open. Windows on the other floors use interior curtains. In the modelling, the vegetation was only considered for the cooling season because there were two trees in the surrounding area.

To validate the model, a weather file was used with average temperatures measured by three external sensors. The validation was based on a comparison of the indoor temperature values obtained by in situ measurement and the core temperature values obtained by numerical simulation. The calibrated period for the winter season was from the 2nd to the 9th of February and for the summer season was from the 9th to the 16th of August. As expected, it was not possible to obtain a perfect match due to the complexity of quantifying all of the issues that the model depends on (Mendes C 2015).

The model was completely successfully validated; it was assumed that the values are due to the difference between the mean indoor temperature value obtained by in situ measurement and the mean temperature value obtained by numerical simulation, which is less than 0.4ºC for both seasons (Mendes C 2015).

The building typology used to validate the model is the same as that used in later solutions with different materials (brick and reinforced concrete elements) during the Modern Movement period in Portugal, so the numerical modelling was used to simulate the other identified cases within the sensibility analysis.

5.4.3.8. Sensibility analysis – Comfort assessment (Mendes C et al. 2015)

The knowledge from the thermal assessment referred to above is extremely important for calibrating the model and increasing its precision. The thermal conductivity and the thickness of the different materials that comprise each construction solution are key factors in determining their thermal inertia and their ability to store or release heat to the interior of the building. This type of issue was analysed during the in situ assessment and is now analysed according to a complementary perspective.

The climate file used for all simulations was an annual file provided by the National Energy and Geology Laboratory that characterises the climatic region. This file compiles average values obtained from a measurement period between 1961 and 1990. The average hourly outdoor air temperature for Aveiro from the database of this file is presented in Figure 5-108 and global horizontal solar radiation is given in Figure 5-109 (Mendes C et al 2015)

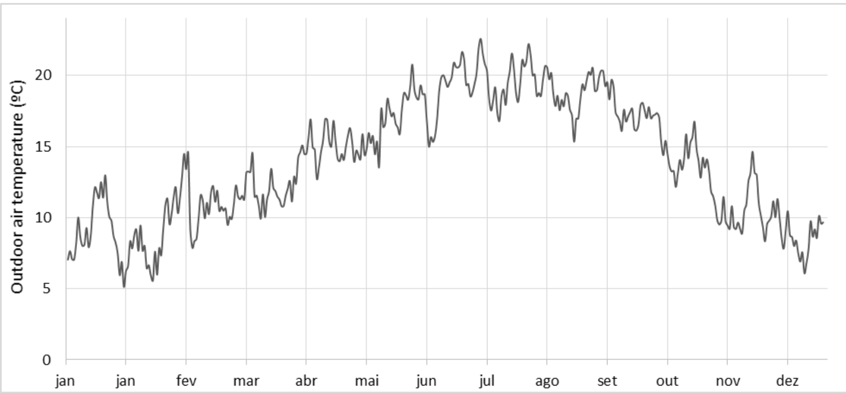


Figure 5-108 - Mean solar radiation values from the database file.

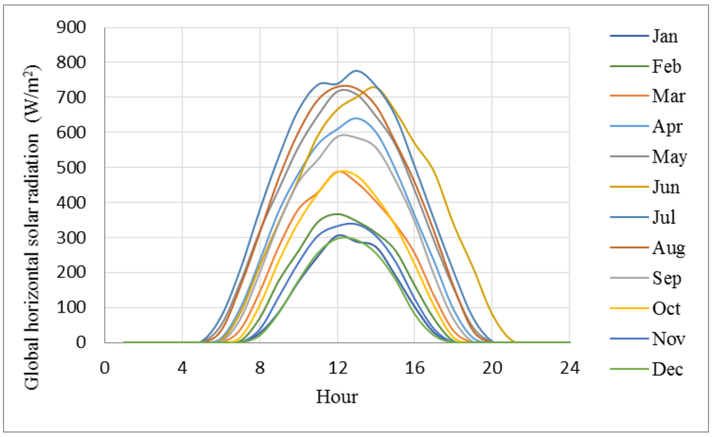


Figure 5-109 – Monthly mean solar radiation

The different thermal parameters were obtained through the collected data during the in situ assessment of the adobe building and in relation to the other ceramic brick solutions used.

The analysis of thermal performance was based on the criteria of comfort defined by standard EN15251 (CEN, 2007). Table 5.5 presents the temperatures for the heating season for all six solutions from the 1st of October until the 9th of April (4584 hours).

Table 5.5 - Temperature and Discomfort Results for the heating season [credits Mendes C., 2015]

Solution	Thermal zone	Mean Temperature (ºC)	Discomfort (%)	Discomfort (h)
SA	ZT4	15.04	97.67	4477
	ZT11	14.52	92.08	4221
	ZT16	13.28	95.24	4366
SB	ZT4	15.15	97.56	4472
	ZT11	14.59	91.86	4211
	ZT16	13.30	95.22	4365
SC	ZT4	15.27	97.23	4457
	ZT11	14.70	91.64	4201
	ZT16	13.33	95.29	4368
SD	ZT4	15.14	97.40	4465
	ZT11	14.55	92.04	4219
	ZT16	13.29	95.24	4366
SE	ZT4	15.03	97.91	4488
	ZT11	14.05	95.57	4381
	ZT16	12.99	96.62	4429

The level of discomfort for two of the thermal zones, TZ11 and TZ4 present a thermal discomfort is slightly improved for solutions B and C. Solution E has a lower comfort level (Figure 5-110).

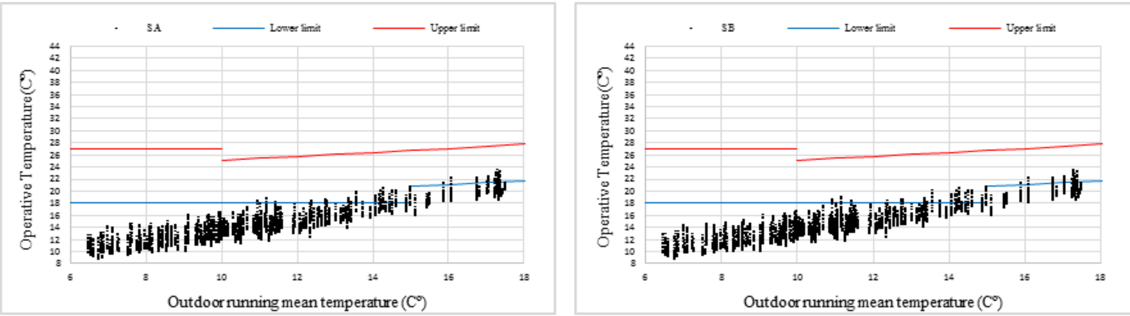


Figure 5-110 - EN 15251 comfort assessment for thermal zone ZT11 [credits Mendes C., 2015]

The analysis of thermal performance was based on the criteria of comfort defined by standard EN15251. Figure 5-111 presents the temperatures for the heating season for all six solutions from the 1st of October until the 9th of April (4584 hours).

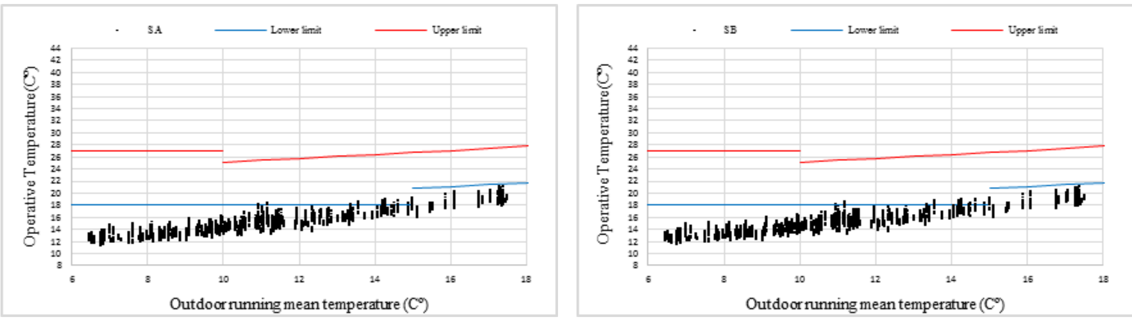


Figure 5-111 - EN 15251 comfort assessment for thermal zone ZT4 [credits Mendes C., 2015]

Table 5.6 presents the temperatures during the cooling season for all six solutions, from the 1st of June to the 30th of September (2829 hours).

Table 5.6 – Temperature and Discomfort Results for the cooling season [credits Mendes C 2015]

Solution	Thermal Zone	Mean temperature (ºC)	Discomfort (%)	Discomfort (h)
SA	ZT4	20.14	82.10	2404
	ZT11	19.98	80.23	2349
	ZT16	21.66	38.08	1115
SB	ZT4	20.05	83.85	2455
	ZT11	21.03	48.84	1430
	ZT16	22.34	24.97	731
SC	ZT4	19.94	85.96	2517
	ZT11	20.97	51.57	1510
	ZT16	22.31	25.20	738
SD	ZT4	20.06	83.13	2434
	ZT11	21.08	46.99	1376
	ZT16	22.36	24.42	715
SE	ZT4	20.23	79.41	2325
	ZT11	21.69	27.49	805
	ZT16	22.77	17.14	502

Figure 5-112 and Figure 5-113 show the level of discomfort for two of the thermal zones, TZ11 and TZ4. The thermal discomfort improves for solutions B, C and D. Solution E improves more than 50% (Mendes C., 2015).

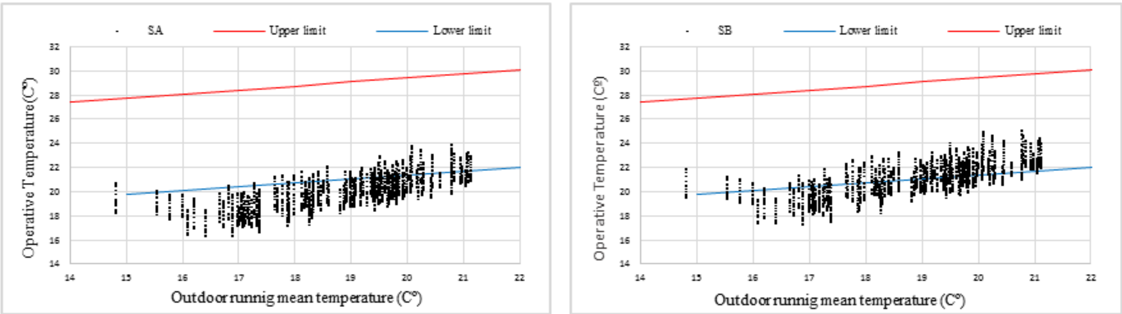


Figure 5-112 - EN 15251 comfort assessment for thermal zone ZT11 [credits Mendes C., 2015]

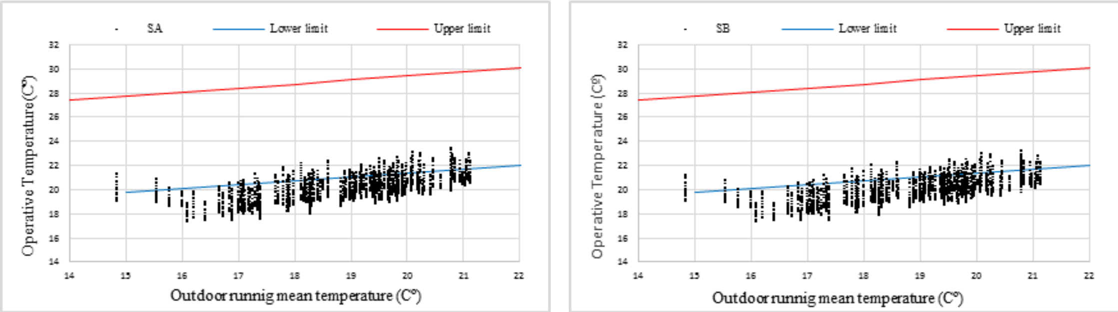


Figure 5-113 - EN 15251 comfort assessment for thermal zone ZT4 [credits Mendes C 2015]

5.4.4. Conclusions and final comments

This research shows that there is not a large difference in performance between the different solutions, which means that thermal insulation from the inside to the outside is necessary to meet comfort requirements from current regulations, namely, during the winter period. These technical facts indicate that all solutions have the same type of issues, which is the need for heat during the winter period. Nevertheless, mixed solution E, adobe on the first floor and brick masonry (double leaf wall), appears to display better thermal behaviour.

In a rehabilitation intervention addressing adobe construction or old brick masonry buildings, the thermal behaviour assessment is crucial for proposing adequate thermal insulation solutions to meet the expected comfort and energy efficiency requirements.

This research has also highlighted that there is no reason in terms of thermal behaviour to demolish adobe houses; these should be rehabilitated to take advantage of their thermal inertia. Taking into account the sustainable character of the adobe construction materials, this research provides relevant data to use in the practice of rehabilitation and to compare with other scientific research on adobe or rammed earth construction issues.

The research work presented here and that being developed is extremely important for the future rehabilitation interventions for these types of buildings, which in turn is a step towards sustainable urban plans. This work has contributed to the maintenance of the adobe built heritage and highlights the importance of its full characterization, including thermal performance assessment and intervention needs.

English Heritage documents their work, and it is interesting to see the criteria being applied to build heritage. This work shows a balance of new solutions in an old fabric that can accomplish the highest purpose of maintaining the cultural value of the building and maintaining as much as possible its authenticity and integrity.

5.5. Analysis of waterproofing barrier solutions (1940-1950) with diatomaceous earth

5.5.1. Introduction

The introduction of diatomaceous earth in mortars as a waterproofing barrier was firstly reported in licensed architectural plans after 1945 in the central region of Portugal. This region is characterised by traditional earthen architecture; however, in most situations, the architectural plans were proposed by civil engineers from the north of Portugal, namely, from Porto, a region with traditional stone masonry construction. Further research by the author in the archives of Porto concluded that diatomaceous earth was used in this type of construction in Porto until at least the 1950s. The reason behind this particular use over this short period of time is not fully understood. It is known that the Second World War made access to some construction materials difficult, even in countries that were not directly involved in the war such as Portugal. As a consequence, some changes were introduced in traditional and engineered construction systems to overcome the temporary lack of materials (Tavares et al. 2012a). This could be the case for the introduction of diatomaceous earth in waterproofing barriers during the 1940s in Portugal rather than a crude oil substitute. The crude oil substitute was applied before 1940 in the base of the construction but also in the exterior walls up to a level at least 0.50 m above the ground. In the north of Portugal, it was applied to the entire height of the exterior walls. If access to the crude oil substitute was restricted during this period, it would justify the use of a natural material – diatomaceous earth – that was more readily available in Portugal.

Diatomite has many uses and is a natural material highly appreciated for the improvement of soils because it increases air penetration, water retention capacity, infiltration and other aspects, due to its small particle size, high surface and high porosity (Minerals zone). It is also used as a mechanism for insect and fungus control and to reduce the bulk density of mortars.

This apparent contradiction – the use of an absorbent material in the construction of a waterproof barrier – was prescribed by technicians who understood the need to control humidity in a region with a high phreatic level.

The present study aims to contribute to the understanding of the role of diatomaceous earth in waterproofing barrier solutions for that time period and to assess its effectiveness for earthen construction barriers. To fulfil this goal, several mortar solutions were prepared based on the previously identified data and analysed using a number of different characterization techniques, namely, capillary measurements, mercury intrusion porosimetry measurements, DRX and FRX of the sample materials and other complementary tests.

One of the most disseminated pathologies in the earthen construction of this coastal region is associated with defects due to rising damp in these heritage buildings. This particular problem is also observed in many other regions and even with other construction systems such as stone masonry. For this reason, this research is important not only as a historical record of the evolution of the construction system but also to understand the natural capacity of this material to improve the performance of building barriers against rising damp and to potentially promote its use in new rehabilitation actions for this type of buildings. The interest in lime mortars research is growing and has been carried out in order to achieve proper combinations for rehabilitation of heritage buildings (Veiga R. et al, 2009).

5.5.2. Composition of the waterproofing barriers of the 1940's in earthen construction

In order to fulfil the objective of characterization of the main compositions of joint mortars from the 1940-1956 periods were assessed and more than 725 architectural files of the Aveiro district archives were analysed. The most used diatomaceous earth solution also involved cement. During the selected study period (1940-1959), other solutions were also used, employing other binders such as air lime. After 1945, airlime was gradually substituted by hydraulic lime in mortars, namely, in waterproofing barriers. In this study, the most common solutions were used to understand the interaction between these binders with the supplementation of diatomaceous earth. The ratio proportions (volumetric percentage) were normally 1:3 (binder: aggregate), to which 5% diatomite in terms of the total volume was added. In other cases, hydraulic lime binder was used in a specific ratio of 1:2 just for this type of barrier. In the written architectural plans, it was not possible to confirm whether the diatomaceous earth used was calcined or not calcined; therefore, this study involves both states of diatomite. This study uses dolomitic air lime that was previously hydrated for the laboratory tests. The crude oil substitute used as waterproofing material was also added to the solutions of the study. The tested solutions were the most common: one with cement and another with hydraulic lime (specifically NHL3.5 type).

The *in situ* assessments and also the descriptions from the archive documents showed that the waterproofing barrier was applied below the floor structure. This occurred independently of the type of structure – timber beams or concrete slabs. Nevertheless, when a substitute of crude oil was added, it was applied below the waterproofing mortar. For this reason, the test specimens follow the same strategy.

The following solutions were used for the study with specific ratio - Table 5.7:

Table 5.7 - Table of identification of specimens type and ratios [credits Alice Tavares]

TABLE OF IDENTIFICATION OF SPECIMENS TYPE AND RATIOS

	Identification of specimen	**Binder**	**Aggregate**	**5% diatomite**	**Description**
Base Solutions	**Ca**	1	3	-	Dolomitic air lime/sand
	Ci	1	3	-	Cement/sand
	CH	1	3	-	Hydraulic lime/sand
Solutions with diatomite (diatomaceous earth)	**CaDn**	1	3	X	Dolomitic air lime/sand + diatomite (not calcined)
	CiDn	1	3	X	Cement/sand + diatomite (not calcined)
	CiD	1	3	X	Cement/sand + diatomite (calcined)
	CiDnB	1	3	X	Cement/sand + diatomite (not calcined) + crude
	CHDn	1	3	X	Hydraulic lime/sand + diatomite (not calcined)
	CHD	1	3	X	Hydraulic lime/sand + diatomite (calcined)
	CHDt	1	2	X	Hydraulic lime/sand + diatomite (calcined)
	CHDnB	1	3	X	Hydraulic lime/sand + diatomite (not calcined) + crude

5.5.3. Laboratory tests

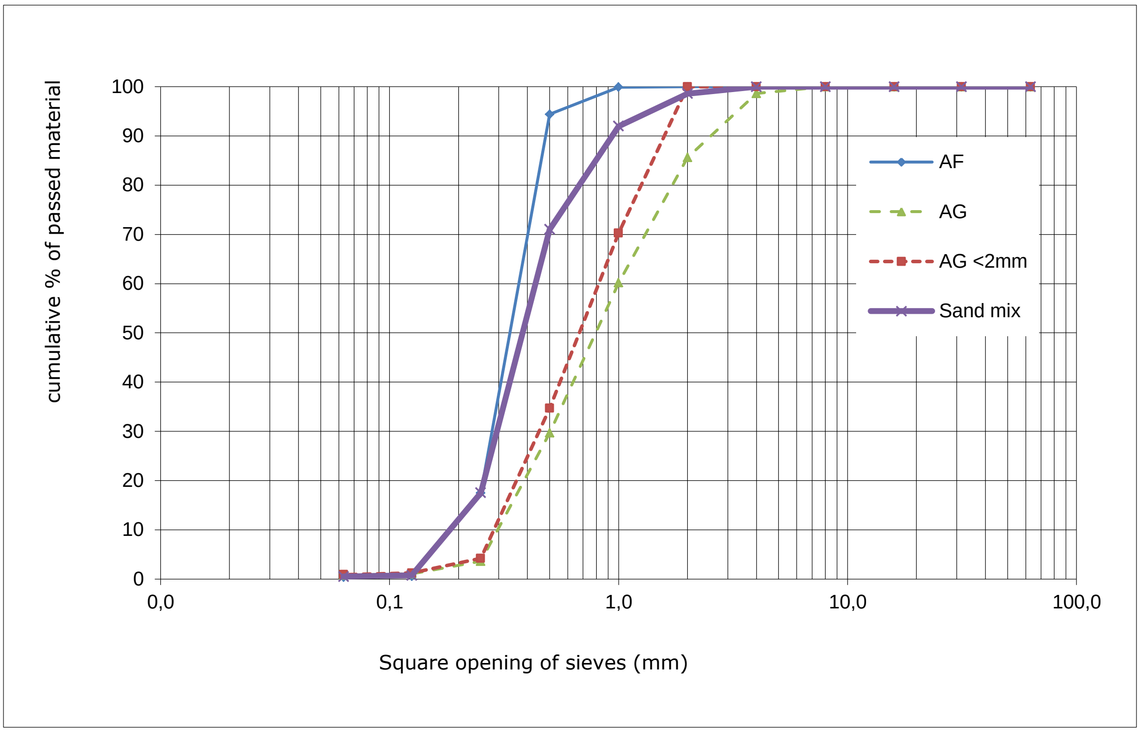
This assay was conducted according to the procedure of AASTHO: T162-04 – ASTM C 305-99 – Mechanical mixing of hydraulic cement pastes and mortars of plastic consistency –for the preparation of mortars. The capillarity tests were conducted taking into account the recommendations of EN 15801 and EN 1015-18, 2002.

5.5.3.1. Characterization of the specimens materials

Sand particle size distribution & calibration

The sand used was calibrated using a mixture of two types of sand from the region, sand from Vale de Ílhavo (AF - 75%) and sand from Salgueiro (AG - 25%) to achieve a grading curve that allowed for a higher type of grains (up to a dimension of approximately 2 mm).

Table 5.8 - Table of calibration of sand [credits Alice Tavares]



The dolomitic air lime characterization

The dolomitic air lime used, had the following chemical composition as indicated by the producer (Lusical – ref. Tudimag):

- $CaO \geq 50\%$

- $MgO \geq 25\%$

- $SiO2 \leq 2\%$

- $S \leq 0.5\%$

- Loss on ignition - $\leq 10\%$

The dolomitic air lime was hydrated during three days before the preparation of the specimens.

Hydraulic lime characterization

The type of hydraulic lime used was NHL3.5 (Natural lime, SECIL, following NP EN459-1), with the characteristics present in Table 5.10.

Table 5.10 – Characterization of NHL3.5

TABLE OF CHARACTERIZATION OF NHL 3.5				
Density (g/cm^3)	**SO_3 (%)**	**$Ca(OH)_2$ (%)**	**Compressive strength (MPa)**	**Particle size distribution (%)**
2,7	$\leq 2,0$	$\geq 25,0$	$\geq 3,5$ and ≤ 10	90µm $\leq 15,0$; 200µm $\leq 2,0$

Diatomaceous earth (not calcined)

Diatomite (diatomaceous earth) is a powdery, non-metallic mineral composed of fossilized skeletal remains of microscopic single-cell aquatic plants called diatoms, each with its own distinct shape, ranging in size from under 5 microns to over 100 microns (IMA Europe). The chemical composition and the physical structure of diatomite allow a wide spectrum of uses, including filter aids, functional fillers and as a component of aggregates (IMA Europe).

The diatomaceous earth (from Portugal) was prepared to remove impurities, after which it was ground until a medium diameter of 10 microns was achieved.

Calcined diatomaceous earth

These products are produced from the natural material by calcination, or sintering, at higher temperatures usually in excess of 900o C in a rotary kiln. After calcination, the diatomite is further processed into products with selected particle size ranges that can include filter aids, multifunctional fillers and aggregates. During calcination any organics and volatiles are removed and the colour typically changes from off-white to tan or pink (IMA Europe), as it is the case of the calcined diatomite used in this research.

The calcined diatomaceous earth was imported from China with a median particle diameter 12,5 microns.

5.5.3.2. Specimens preparation

The specimens are constituted of two parts of an adobe block and a layer of mortar with the specified composition (Table 5.9). The material used was obtained from an adobe building in the region that had been assigned to demolition by the Town Council. This rural building at Gafanha da Nazaré (Ilhavo town) had just one floor, and the adobes to produce the specimens were removed from an interior adobe wall (a loadbearing wall in the middle of the construction and with longitudinal orientation). The adobe blocks were taken from a level higher than 1.0 m to avoid the eventual effects of rising damp on the adobe blocks.

5.5.3.3. Adobe blocks

The adobe blocks from an existent dwelling were cut into cubes with sides of approximately 8,0 cm. However, due to the dimensions and the characteristics of the material, it was not possible to have precisely the same dimension along each side. Therefore, samples (cubes) were numbered, weighed, and measured along each side (Figure 5-114). These blocks were dried for three weeks at the laboratory in natural environmental conditions before the next step of preparation of the specimens for the laboratory tests.

Figure 5 -114 Adobe blocks cut and numbered for the specimens blocks

5.5.3.4. Mortars (calibration of the materials)

The mortar preparation was executed under the guidelines of the American normative ASTM C 305-99 (Mechanical mixing of hydraulic cement pastes and mortars of plastic consistency). Therefore, the process of progressive mixture and mixing periods followed this normative. The materials, aggregate, binder and diatomite, were mixed in an electrically driven mechanical mixer of epicyclical type with two speeds (Figure 5-115).

The preparation of all samples (mortars and specimens) was performed on the same day under the same environmental conditions. Potable water was used for the mixture. In the preparation process, an extra 2% of water was added to the mixture with hydraulic lime to achieve a better consistency.

Figure 5 -115 - Mechanical mixer of epicyclical type with two speeds used

After the preparation of each mortar type, a bulk spread was performed and the results obtained are presented in the following Table 5.9.

Table 5.9 - Table of bulk spread values of the mortars [credits Alice Tavares]

TABLE OF BULK SPREAD VALUES OF THE MORTARS

	Identification of specimen	**Binder ratio**	**Aggregate ratio**	**Bulk spread value**	**Description**
Base Solutions	**Ca**	1	3	140	Dolomitic air lime/sand
	Ci	1	3	170	Cement/sand
	CH	1	3	155	Hydraulic lime/sand
Solutions with diatomite (diatomaceous earth)	**CaDn**	1	3	140	Dolomitic air lime/sand + diatomite (not calcined)
	CiDn	1	3	160	Cement/sand + diatomite (not calcined)
	CiD	1	3	165	Cement/sand + diatomite (calcined)
	CiDnB	1	3	160	Cement/sand + diatomite (not calcined) + crude
	CHDn	1	3	155	Hydraulic lime/sand + diatomite (not calcined)
	CHD	1	3	150	Hydraulic lime/sand + diatomite (calcined)
	CHDt	1	2	170	Hydraulic lime/sand + diatomite (calcined)
	CHDnB	1	3	147	Hydraulic lime/sand + diatomite (not calcined) + crude

5.5.3.5. Specimen Composition

For each type of solution six (combined) specimens were coupled for the laboratory test, an additional (combined) specimen for future comparisons and other specimens composed solely by mortar in order to offer initial results about its mechanical characteristics.

Each specimen is composed of 2 cubes with a 2,0 cm thick layer of mortar between them. The specimens were prepared on the same day by the same person. All of the specimens were identified and numbered with the code given to each solution (ex: CHD1, CHD2, CHD3, etc).

After this preparation process, the specimens dried in a conditioning chamber with controlled temperature 20ºC and humidity of 65% RH for 60 days, following the period recommend by European regulation EN 1015-18 (Methods of test for mortar for masonry. Part 18: Determination of water absorption coefficient due to capillary action of hardened mortar). The specimens with hydraulic lime were subjected to different conditions of 20ºC and 95% RH for the same period. .

After this period, they were dried at 60ºC in a climatic chamber until constant mass was achieved (at a minimum of 72 hours prior to the test). They were then measured and weighed prior to the test. The submerged base area was measured to a precision of 0.1 mm.

The specimens were placed in a recipient under a layer of sponge; there were six samples in each recipient. Distilled water was added to submerge the base of the specimens to a height level of 10 mm, following regulation (EN 1015-18).

At time points representing 1, 5, 10, 15, 30, 60, 480 and 1440 minutes, each specimen was weighed and the respective wet front level was assessed. Each sample had a slightly different time point zero to allow for proper measurement of the subsequent time points.

Each sample piece was pulled up successively, the submerged part was gently wiped with a damp cloth to remove water drops, and it was immediately weighed to an accuracy of 0.01 g. The time span from the start of the test until the weighing time was recorded. The weighing protocol was held for 24 hours. The samples for which the wetted height did not reach the intermediate area of the test mortar had their testing time extended until this event took place, which could require an additional 24 hours.

The height of the water was kept constant throughout the test, with the corrections performed after the samples were weighed.

Temperature and humidity conditions were recorded throughout the testing procedure, with values raging from around of 16ºC to 17.3ºC and 65%H.

5.5.3.6. Mechanical characteristics of the mortars used in the specimens (Figure 5-114)

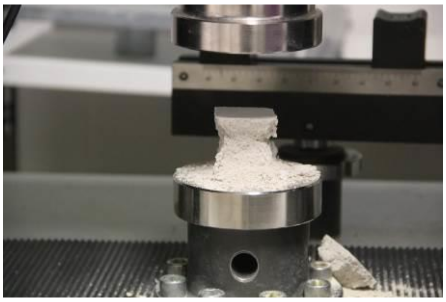


Figure 5-114 – Compression test [credits Alice Tavares]

The Table of the mechanical properties of mortars indicate the relevant influence of diatomite in all the samples. Another issue for taking in account is the additional influence of changing ratio – CHDt in comparison with CH (Table 5.10).

Table 5.10 - Table of compression and flexural values [credits Alice Tavares]

TABLE OF COMPRESSION and FLEXURAL VALUES (Specimens with 90 days)				
	Identification of specimen	**Medium strength N/mm2**	**Medium flexural strength N/mm2**	**Rupture sec**
Base Solutions	**Ca**	1.745,36	1,09	18,63
	Ci	17.141,10	10,71	102,43-
	CH	3.009,74	1,88	22,15-
Solutions with diatomite (diatomaceous earth)	**CaDn**	1.482,45	0,93	17,23
	CiDn	18.872,4	11,8	117,55
	CiD	20.995,30	13,12	128,02
	CHDn	3.4290,79	2,14	24,90
	CHD	3.223,33	2,01	24,45
	CHDt	6.577,19	4,11	46,15

5.5.3.7. Mercury intrusion porosimetry results

The mercury intrusion porosimetry test was conducted by the IPN Led & Mot Laboratory using AutoPore IV equipment from Micromeritics operating in a pressure range between 1.0 psia and 33.000 psia, allowing for the intrusion of mercury into pores with diameters ranging between 360 µm for minimal pressure and 5.5 nm for maximum pressure. This procedure was in accordance with the norm ISO 15901-1:2005. The barrier mortars, CaDn, Ci, CiD, CiDn, CHD, CHDn and CHDt, were assessed at 28.01.2015 (50 days after their preparation). The equipment used was the AutoPore IV from Micromeritics. The results are summarized in Table 5.12.

Table 5.12 – Rsults of mercury invasion porosimetry

SAMPLE	**CaDn**	**Ci**	**CiD**	**CiDn**	**CHD**	**CHDn**	**CHDt**
Total intrusion volume (≈0.5 – 33 000 psia) (ml/g)	0.1937	0.1129	0.1117	0.1497	0.1362	0.1470	0.1322
Median pore diameter (volume) (µm)	**23.8311**	1.4014	1.4384	2.0462	1.2420	1.2442	0.5874
Average pore diameter (4.V/A) (µm)	0.3687	0.2099	0.1509	0.1578	0.2040	0.2582	0.1075
Bulk density (g/ml)	1.7156	1.9953	1.9539	1.8217	1.8429	1.8214	1.9041
Apparent density (33 000 psia) (g/ml)	2.5694	2.5751	2.49955	2.5048	2.4605	2.4872	2.5447
Porosity (%)	**33.2284**	22.5170	21.8287	27.2723	25.1010	26.7701	25.1736

[credits Alice Tavares]

The Figures below show the porosimetry of the mortars used in the specimens. It can be seen that both changes in diatomite addition (non calcined versus calcined diatomite) and ratio have impact on the dimension/distribution of the pore size diameter of the mortars. The main difference is of CaDn and again the fact that diatomite is calcined or not, changes the porosimetry characteristics, as expected.

CaDn

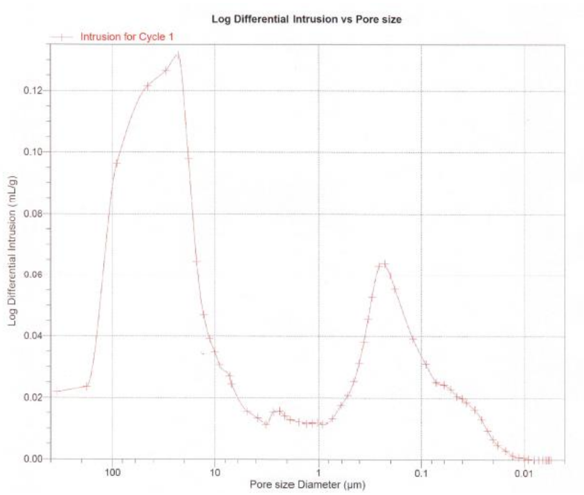


Figure 5-115 – Results of porosimetry CaDn [credits Alice Tavares]

CHD

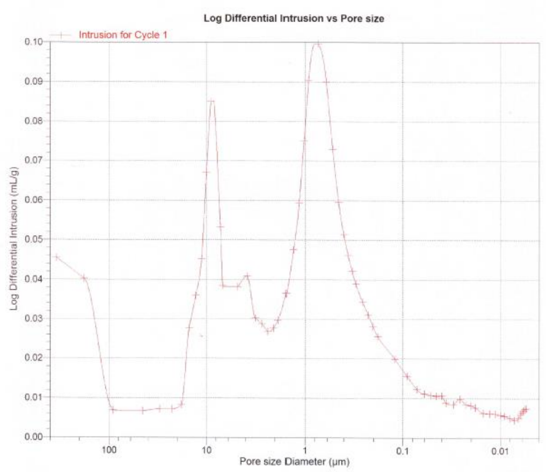


Figure 5-116 – Results of porosimetry CHD [credits Alice Tavares]

CHDn

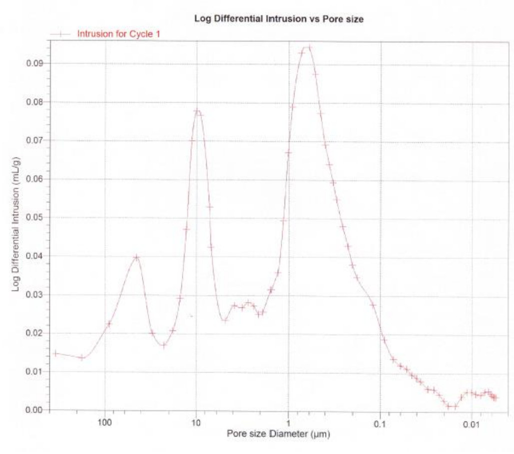


Figure 5-117 – Results of porosimetry CHDn [credits Alice Tavares]

CHDt

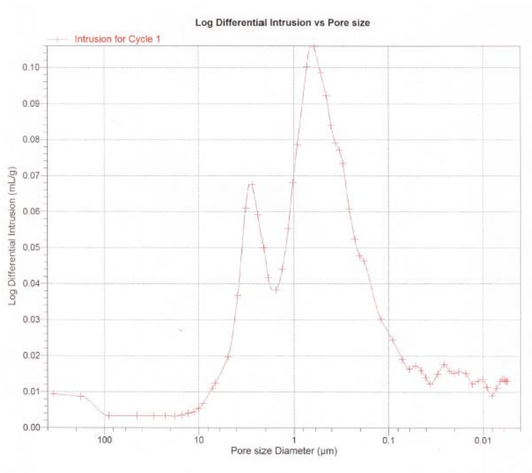


Figure 5-118 – Results of porosimetry CHDt [credits Alice Tavares]

Ci

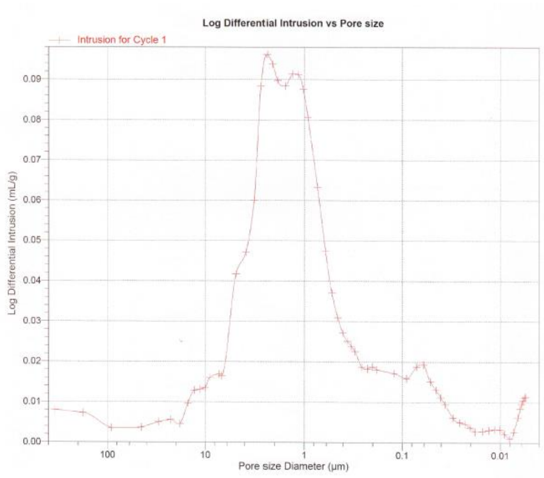


Figure 5-119 – Results of porosimetry Ci [credits Alice Tavares]

CiD

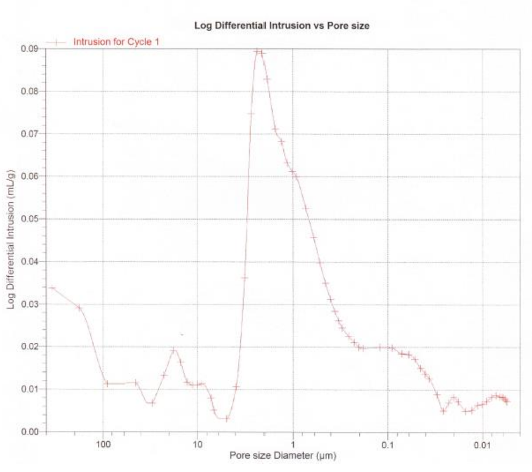


Figure 5-120 – Results of porosimetry CiD [credits Alice Tavares]

CiDn

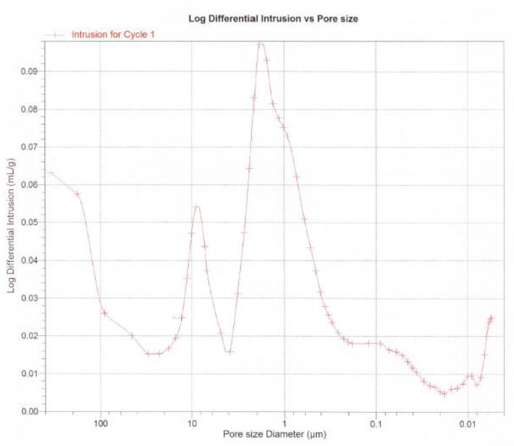


Figure 5-121 – Results of porosimetry CiDn [credits Alice Tavares]

5.5.3.8. Results of capillary absorption and capillary penetration tests

The data collected during the test included record of colours to identify the passage of the wet front through the barrier: white- in the inferior adobe; yellow – close to the barrier; orange – in the barrier; red – surpass the barrier; brown – at the top of the specimen (Figure 5-122). This procedure was taken for all the samples with digital photo record. The collection of data (weighing and photo record) continued after the 24 hours of the standard test until 48 hours.

pr EN 15801

CADn	m_s [g]	A		t_i [min]	1	5	10	15	30	60	90	120	150	180	240	300	360	420	480	540	600	720	1440
1		b [cm]	7,9	m_i [g]	1929,55	1948,24	1965,54	1976,91	1991,29	2019,32	2031,05	2041,92	2051,31	2059,68	2071,92	2082,1	2088,99	2095,78	2100,5	2103,58	2105,66		2116,45
		l [cm]	8	H_i [cm]	2,5	4,1	5,5	6,2	8	10	11,5	12,5	13,8	14,7	15,7	17	18	18,2	18,2	18,2	18,2		18,2
	1893	A [m2]=	0,0063	Q_i [g/m²]	5735,76	8693,04	11430,38	13229,4	15504,7	19939,9	21795,9	23515,8	25001,58	26325,9	28262,7	29873,4	30963,6	32038	32784,81	33272,152	33601,27		35308,5
2		b [cm]	8	m_i [g]	1968,73	1974,4	1978,2	1981,3	1988,0	1998,9	2006,1	2014,4	2020,9	2026,9	2036,7	2044,3	2049,6	2055,2	2060,04	2064,86	2068,91		2119,04
		l [cm]	7,9	H_i [cm]	2,1	2,9	3,7	4	5	6,5	7,3	8,2	8,8	9,3	10	10	10,5	12,2	12,5	13,2	13,5		18
	1954	A [m2]=	0,0063	Q_i [g/m²]	2393,99	3295,89	3892,405	4389,24	5443,04	7161,39	8299,05	9618,67	10655,06	11598,1	13142,4	14343,4	15182	16071,2	16841,77	17604,43	18245,25		26177,2
3		b [cm]	8,1	m_i [g]	1997,4	2002,3	2006,2	2009,4	2017,0	2029,1	2038,9	2048,0	2055,9	2062,3	2072,9	2081,4	2087,5	2093,2	2097,42	2101,69	2105,04		2143,63
		l [cm]	8,1	H_i [cm]	2	2,4	2,7	3,2	3,8	5,7	5,8	6	7	7,7	9	9	10,5	10,8	11,3	11,7	12,1		16,5
	1982	A [m2]=	0,0066	Q_i [g/m²]	2331,96	3080,32	3673,221	4167,05	5319,31	7158,97	8652,64	10044,2	11245,24	12220,7	13845,5	15141	16058,5	16933,4	17576,59	18227,404	18738		24619,7
4		b [cm]	7,5	m_i [g]	1916,80	1940,61	1957,61	1965,50	1977,68	1987,50	1993,85	1998,92	2003,27	2008,59	2016,61	2024,82	2031,4	2036,9	2043,18	2053,18	2061,96	2064,31	2082,56
		l [cm]	8	H_i [cm]	3,4	5	5,6	6,5	7,8	9	10,5	11,2	12,3	13	13,4	14,5	15,7	16,1	17,3	17,9	17,9	17,9	17,9
	1870	A [m2]=	0,006	Q_i [g/m²]	7816,67	11785	14618,33	15933,3	17963,3	19600	20658,3	21503,3	22228,33	23115	24451,7	25820	26908,3	27826,7	28880	30546,667	32010	32401,7	35443,3
5		b [cm]	8	m_i [g]	1934,66	1942,78	1947,58	1950,79	1958,58	1970,91	1978,86	1986,19	1992,67	1998,89	2009,66	2018,79	2025,9	2031,8	2037,33	2046,48	2054,16	2057,27	2091,83
		l [cm]	8	H_i [cm]	2,4	3,1	3,5	3,6	4,1	4,4	5,8	6,7	7,1	7,9	9,5	9,5	10,3	11,2	11	12	13	13	14,5
	1918	A [m2]=	0,0064	Q_i [g/m²]	2618,75	3887,5	4637,5	5139,06	6356,25	8282,81	9525	10670,3	11682,81	12654,7	14337,5	15764,1	16879,7	17800	18660,94	20090,625	21290,63	21776,6	27176,6
6		b [cm]	8,1	m_i [g]	1999,43	2006,84	2011,43	2014,70	2022,84	2033,80	2039,75	2045,75	2050,53	2055,53	2064,32	2072,31	2079,0	2084,1	2089,31	2097,0	2103,58	2106,26	2134,06
		l [cm]	7,9	H_i [cm]	2	3	2,7	3,5	3,9	5,8	5,6	6,5	6,7	6,5	7	7,8	8,6	9,8	10,5	10,9	12,9	12,9	14
	1984	A [m2]=	0,0064	Q_i [g/m²]	2395,69	3553,68	4270,98	4782	6054,07	7766,84	8696,67	9634,32	10381,31	11162,7	12536,3	13785	14822,6	15627,4	16441,63	17643,382	18671,67	19090,5	23434,9
				Média Hi [cm]	2,4	3,41667	3,95	4,5	5,43333	6,9	7,75	8,51667	9,283333	9,85	10,7667	11,3	12,2667	13,05	13,46667	13,983333	14,6	14,6	16,5167
				Média Qi [g/m2]	3882,14	5715,9	7087,136	7940,02	9440,13	11651,6	12937,9	14164,4	15199,06	16179,5	17762,7	19121,1	20135,8	21049,4	21864,29	22897,443	23759,47	24422,9	28693,4

Figure 5-122 – Example of the data record of capillary tests [credits Alice Tavares]

<u>Legend:</u> White – wet front in the inferior adobe block; Yellow – wet front close to barrier; orange – wet front in the barrier; red – wet front passed the barrier

5.5.3.9. Capillary penetration coefficient

The height of the wet front of the specimens (lateral side) was measured at each time point.

The following Figures show the mean values results of capillary tests of some of the specimens (Figure 5-123 to Figure 5-133).

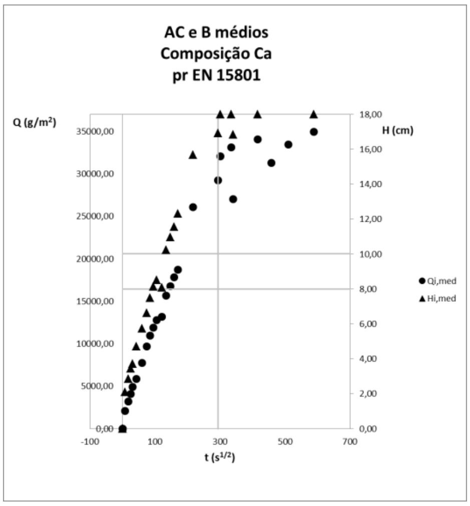


Figure 5-123 – Capillary – Ca [credits Alice Tavares]

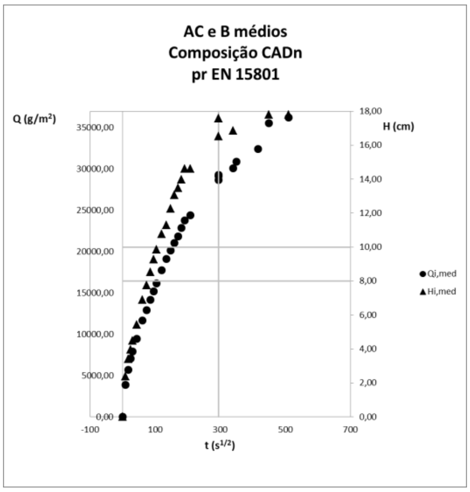


Figure 5-124 – Capillary CaDn [credits Alice Tavares]

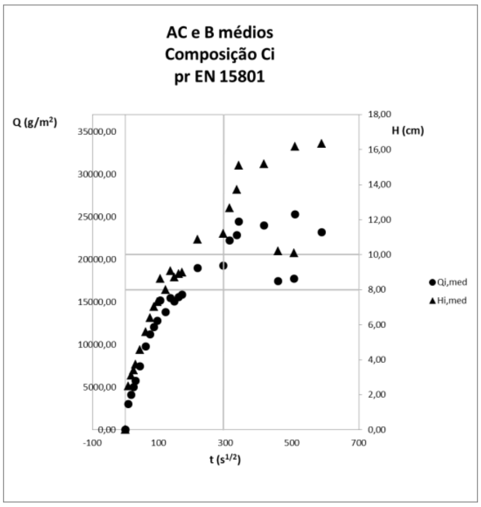


Figure 5-125 – Capillary Ci [credits Alice Tavares]

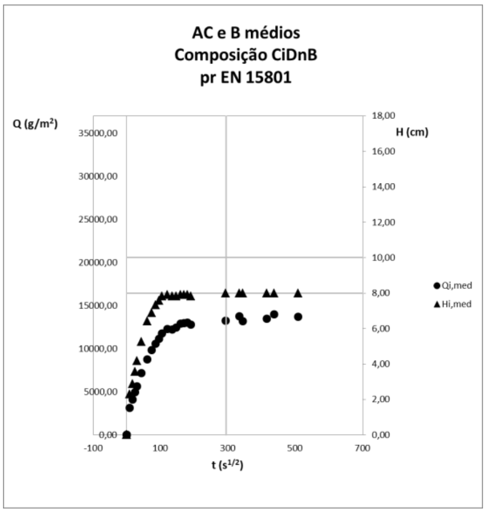


Figure 5-126 – Capillary CiDnB [credits Alice Tavares]

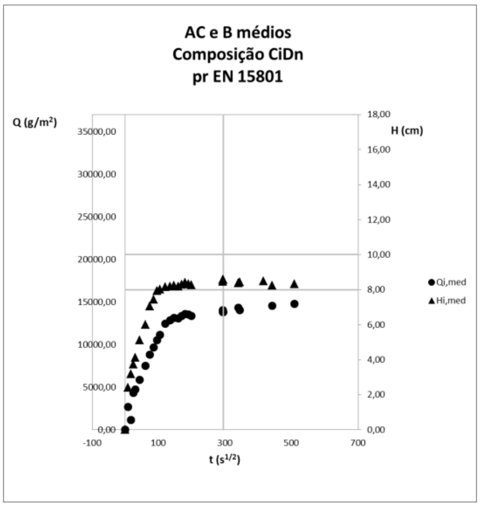


Figure 5-127 – Capillary CiDn [credits Alice Tavares]

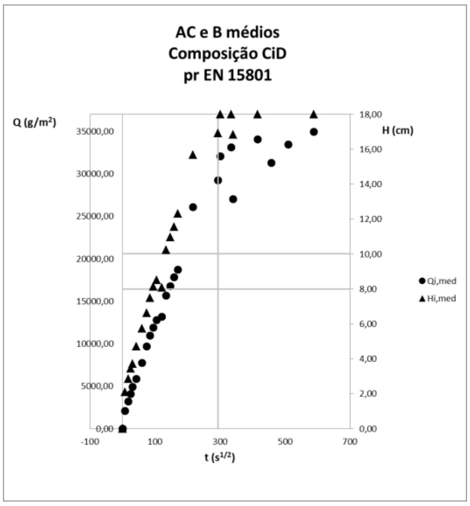


Figure 5-128 – Capillary CiD [credits Alice Tavares]

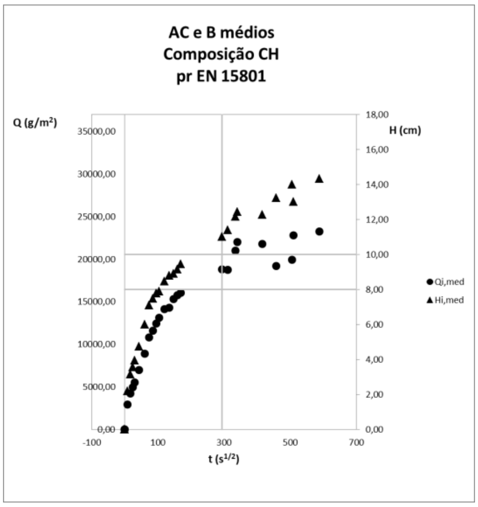


Figure 5-129 – Capillary CH [credits Alice Tavares]

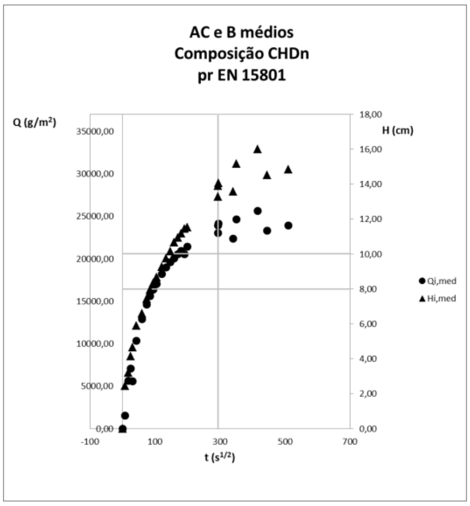


Figure 5-130 – Capillary CHDn [credits Alice Tavares]

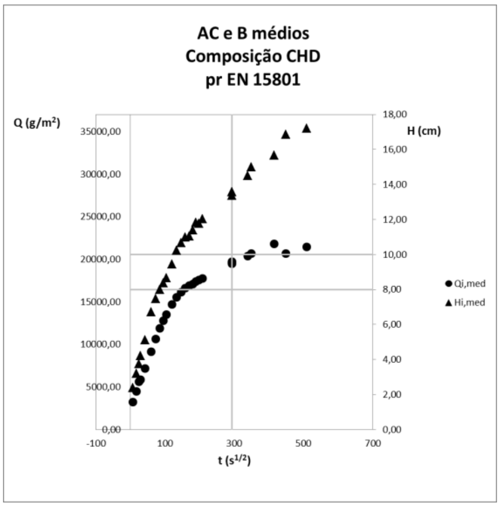


Figure 5-131 – Capillary CHD [credits Alice Tavares]

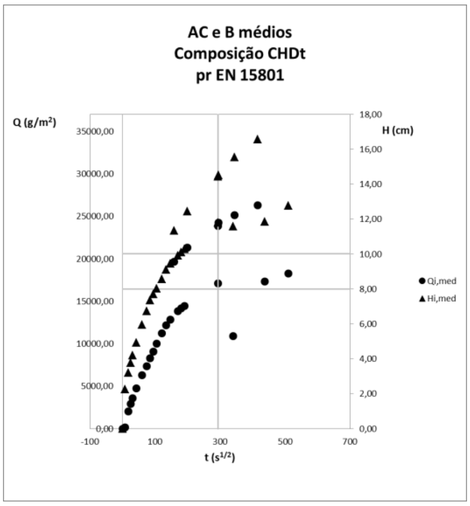


Figure 5-132 – Capillary CHDt [credits A.Tavares]

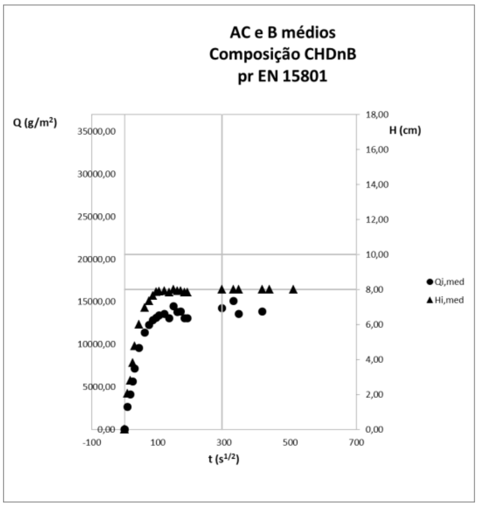


Figure 5-133 – Capillary CHDnB [credits Alice Tavares]

5.5.4. Preliminary results of tests

The preliminary conclusions from the visual assessment throughout the duration of the lab test are as follows.

- For the formulations with air lime, for Ca specimens, the wet front quickly reaches the mortar barrier, and the passage to the second adobe block of the sample is also rapid, at under 2 hours. The wet front reaches the top level of the specimens within the 24 hours of the test. For CaDn, the barrier wet front was reached more quickly (0.5-1 hour) and the barrier was surpassed in almost 2 hours. However, in comparison with the previous solution, after the barrier was surpassed, the wet front progression was slower and did not reach the top of the specimen within the 24-hour period. This was only observed after the first 24-hour period.

Thus, the addition of Dn to air lime mortars suggests three preliminary conclusions:

1. Dn affects the progression of the wet front, initially increasing the rising speed of the wet front until the barrier, which suggests the possibility of other interaction effects to be assessed in future assays.

2. Dn does not stop the progression of the wet front.

3. Dn influences the progression speed when the wet front reaches or surpasses the barrier, accumulating within the rising damp.

In relation to the compositions with hydraulic lime, CH, the wet front reached the barrier in 90-120 minutes and the passage through the barrier was faster (30-120 minutes). However, the material (adobe) of one specimen delayed this progression more than 6 hours. Until 24 hours had passed for the test, it was observed that half of the samples presented a wet front in the barrier and the other half had surpassed the barrier, but only to the level of the second adobe block. The extra 24 h period did not change this situation, as the wet front did not reach the top of the specimen in any of the samples. This result is in accordance with hydraulic lime's known capacity to decrease the wet level front; however, it also showed that it was not sufficient in terms of the waterproof barrier.

The addition of Dn to the hydraulic lime mortars suggests three preliminary conclusions:

1. The progression of the wet front is faster; however, the non-reproducibility of the results is also higher (less than 30 minutes in some of the samples).

2. The non-reproducibility of results was also observed regarding the influence of the barrier, as half of the samples had a wet front that remained in the barrier more than 6 hours, as opposed to some samples for which it surpassed the barrier in just 1 hour.

3. Dn does not appear to have much influence regarding the wet front, as it had a similar profile to the sample without Dn, for which the wet front only reaches half the height of the second adobe block even after the extended 24 hours.

The addition of D to hydraulic lime mortars suggests three main preliminary conclusions:

1. The wet front progression was more homogeneous in the six samples (in relation to the Dn solutions) and reached the barrier within 90-120 minutes, where it stayed for more than 0.5-1 hour.

2. The wet front remains for a longer period of time in the barrier than the solutions with Dn or without D (CH).

3. The wet front completes the barrier level in less than 8 hours and stays at the middle level of the second adobe block through the extended 24 h.

4. The change of ratio (1:2 – hydraulic lime: aggregate + D) delayed the progression of the wet front (reaching the barrier in 120-180 minutes and spending more time in the barrier) in comparison to the ratio of 1:3. In two specimens, the wet front did not surpass the barrier until 24 hours. Globally, the wet front did not reach the level of the previous solutions with D.

The specimens with Ci presented a different wet front rising speed than those reported for Ca and CH, where a slower progression was observed, staying for more than 1.5-3 hours at the low level of the barrier. The results show that the wet front did not surpass the barrier in 24 hours, but only after the extra 24 h in half of the samples. Only in one sample did the wet front reach the top. The absorption is lower than in the Ca solution.

The addition of Dn to cement mortars suggests three preliminary conclusions:

- The wet front shows a more homogeneous progression in the 6 samples;

- The wet front stays for a longer period immediately above the barrier, in some samples for up to 5 hours;

- After the first 24 hours, the barrier revealed a very low humidity in the transition to the adobe above. Within the extra 24 h, only some of the samples presented a wet front in the middle of the barrier level, while others maintained the level below the barrier.

The addition of D to cement mortars suggests three preliminary conclusions:

- The wet front progression presented a more homogeneous progression in the 6 samples.

- The wet front stayed for less time than the Dn solution in the transition area of the barrier, surpassing this level in 1-2.5 hours.

- The wet front did not surpass the barrier after the extra 24 h. The CiD solution can be considered to be a waterproof barrier. Some samples had a wet front slightly below the barrier.

The addition of crude substitute to the CiDn and CHDn solutions is an effective complement to waterproof barriers. The progression of the wet front is similar to the solution without B until it reaches the level of the barrier. The lower adobe blocks reached almost total saturation within the 24-hour period. Although there was some slight disaggregation of these adobes at the end of the test, both solutions maintained their integrity and the specimens did not break around the area of the level of the crude substitute. Both solutions presented dry barriers at the end of the testing period (48 hours).

5.5.5. Discussion of results

From the analysis of the previous tables, it can be observed that in the mortars with lime (air lime or hydraulic lime) and diatomite – CaDn, CHDn, CHD and CHDt –the wet front reaches the barrier more quickly in comparison to the other solutions. The CaDn and CHDn solutions showed that the barrier did not had any effect in blocking the wet front, which progressed at almost the same speed as up the adobe block. On the contrary, the wet front in CiDn, CiDnB, and CHDnB presented a delay alongside the barrier, without passing it throughout the entire test. This showed the effectiveness of these solutions. However, the Ci, CiD and CHDn solutions showed that the wet front remained a much longer time inside the barrier than it did for the other solutions. The CH and Ci solutions presented the longest delay in surpassing the barrier.

The cement solutions with D or Dn presented a lower absorption level (gained less weight). The same was observed for the Ca and CaDn solutions, although with a less evident difference in water absorption.

The addition of D anticipates the wet front rising to the barrier in all of the solutions, which happened in approximately 2 hours, with the exception of CHDnB. At the end of the test (24 hours), the wet front level is higher (approximately 20%) in all of the CH solutions with diatomaceous earth (D and Dn) compared to the samples without this supplement. It should be emphasized that the CHD, CHDn and CHDt solutions presented a diffused wet front. This observation can be justified also by the lower weight gain for these solutions (≈ 6.2 – 8.3 %) and their non-saturation at the end of the test. Although the CH solution presented a lower wet front than CH+D, CH+Dn or CH+DT, the weight gain is similar.

The CHDn solution increased the weight approximately 2% compared to the other CH solutions. The CHDnB solution increased the sample by approximately 4.8% of its initial weight, which shows the saturation of the adobe block below.

None of these solutions, CH, CHD, CHDn or CHDt, can be assumed to be waterproof barriers; however, their performance is better than the Ca and CaDn solutions.

Comparing the Dn and D solutions, it can be concluded that there is more variability in results when not calcined diatomaceous earth (Dn) is applied. It is also possible to conclude that the Dn solutions with cement apparently have a better performance than D because there is a delay in the wet front until reaching the barrier and a longer stay at the frontier. Both solutions presented a delay in the wet front rising to the barrier when compared to the solution without diatomite. This aspect it is not as evident for the CH solutions.

5.5.6. Conclusions and future work

The solutions that can be assumed to be waterproof barriers are the solutions with the crude substitute – CiDnB and CHDnB.

The solutions for which the wet front did not pass above the barrier are CiDn and CiD.

The solutions with fewer samples surpassing the barrier within 24 hours are Ci (in half of the samples); CiDn (no sample was surpassed); CiD (no sample was surpassed); and CHDt (only 2 samples did not surpass the barrier).

The solutions for which the wet front reached the top level of the specimen are Ca (almost all of them) and CaDn (half of them).

5.6. Analysis of the behaviour of waterproof barriers with diatomite in relation to salts effects (NaCl and Na_2SO_4)

5.6.1. Introduction

The effect of salts creates a broad major defect that is present in many of the ancient adobe buildings of the region. The high phreatic level is one reason for salts' occurrence, but other causes are associated with lack of maintenance of the urban water drainage, the lack of perimeter drainage, closing ventilation at the base of buildings and other causes already discussed in chapter 4.

Although efflorescence is commonly present in the base of ancient walls, there are also some cases of other ancient buildings in similar condition for which no evidence of salt is found. To understand the reasons behind this difference, observations at the in situ surveys are being conducted during demolitions mainly in Ílhavo (with the support of the Municipality of Ílhavo, to whom the author is giving assistance during inspection surveys) and in Aveiro. In some cases, a layer of mortar was found in the walls' foundation that was slightly different in relation to the mortars applied in the rest of the mortar rows in that area of construction. The differences are in terms of colour and texture. Some samples were removed from the centenary buildings, and laboratory tests will be conducted over the next months. For this reason, it is not currently possible to present conclusions in relation to this in situ data. Nevertheless, in the cases from which the samples were removed, the application of petroleum as a waterproof barrier was not observed in the building.

One possibility is the application of a different material in addition to the general mortar applied at the time. Because there are a restricted number of archive files for the region prior to 1940 and few files including construction details, it is not currently possible to understand the beginning of this material's use. Nevertheless, during the 1940s and the 1950s, the use of diatomite is mentioned in the archive files, as seen in Aveiro and Porto. The interest in this material is also expressed in the literature and in a USA for the improvement of cement mortars.

One of the first objectives of this study involving diatomite was to understand if, in the case of its inefficient behaviour as a waterproof barrier with D due to its absorbent characteristics, it was instead efficient in the retention of salts. This quality may have confused the technicians, who did not observe the rising of the efflorescence. Furthermore, an objective of this research was to understand the effect that this material can have in diminishing or increasing the effects of salts.

During the previous research on capillary to determine the effectiveness of this addition, it was clear that despite the low percentage of diatomite in certain types of mortars, a very positive change in behaviour was observed.

For this purpose, the same type of capillary laboratory test was conducted again, following the same procedures for 24 hours (the end of the test in the normalization). The samples were the same as for the capillary tests, but they were dried previously until achieving a constant mass.

Additionally, a spectrometry test was also conducted to provide additional information about the presence of salts above the barrier.

However, the following results belong to an initial stage of ongoing research and, for this reason, will need further analysis to achieve more complete conclusions.

5.6.2. Laboratory tests

The weighing was held for 24 hours. The height of the water was kept constant throughout the test, with corrections made as much as possible after weighing the samples.

The entire test was conducted while recording temperature and humidity conditions, which were mostly between the values of 16ºC-17.3ºC and 65%H.

Previous to the beginning of each test, a solution was prepared with the addition of salts to distilled water.

For the tests, 15% NaCl was used following the guidance of the standard. For the tests with Na2SO4 14%, a 10 mm level for the liquid was maintained.

After the Norm requirements were completed, the test continued for another 48 hours, with weighing at the end of 48 hours. Prior to that time, the specimens were photographed and the water level maintained at 1 cm high. After the 48 hours, no liquid was added, but photographs of the samples continued to be taken until 72 hours was reached, after which all of the specimens were weighed.

5.6.3. Results of salt tests for NaCl

5.6.3.1. Introduction

One of the main conclusions is that after 24 hours of testing, the presence of salts in the exterior of the specimens was not much expressed; in some cases, this appeared to almost be a regular capillary test. Only after 24 hours did the effects of efflorescence begin to be evident. Liquid was added until 48 hours was reached; despite the fact that no more liquid was added after that period, the progression of the effects of salts continued even in solutions that entered a slightly dry process.

5.6.3.2. The wet front progression with salts of Ca

In the solution Ca (Figure 5-134) it is shown that the wet front arrive the top of the specimen, although the manifestation of crystallization was not evident in the barrier neither below the barrier. The only record is a slightly matt spot immediately above the barrier with a height of 1 cm approximately, that can be associated with slats effect, eventually crystallization.

48 hours

Figure 5-134 - Results of test – Ca [credits Alice Tavares]

5.6.3.3. The wet front progression with salts of CH

In relation to the CH solution (Figure 5-135), the wet front passed the barrier. Crystallization is not evident below the barrier; however, very thin white crystallization is observed in the barrier, mostly at the interface of the barrier with the adobe above. Nevertheless, it did not fill the entire barrier surface.

Initial 24 hours 48 hours

Figure 5-135 - Results of test – CH [credits Alice Tavares]

5.6.3.4. The wet front progression with salts of Ci

The Ci solution (Figure 5-136) shows that the wet front surpasses the level of the barrier. There is some crystallization in the barrier - a band of 2 cm in height as a matt spot / jellied surface. Above the barrier, there is almost no crystallization, with the exception of a very small amount around some limestone gravel in the aggregate in the adobe above.

Initial 24 hours 48 hours

Figure 5-136 - Results of test – Ci [credits Alice Tavares]

5.6.3.5. The wet front progression with salts of CaDn

The CaDn solution (Figure 5-137) shows that the wet front surpasses the barrier, but crystallization is minimal and very disperse, similar to talcum powder. A transparent film was formed above the barrier without any evidence of crystallization under the film.

Initial 24 hours 48 hours

Figure 5-137 - Results of test – CaDn [credits Alice Tavares]

5.6.3.6. The wet front progression with salts of CiD

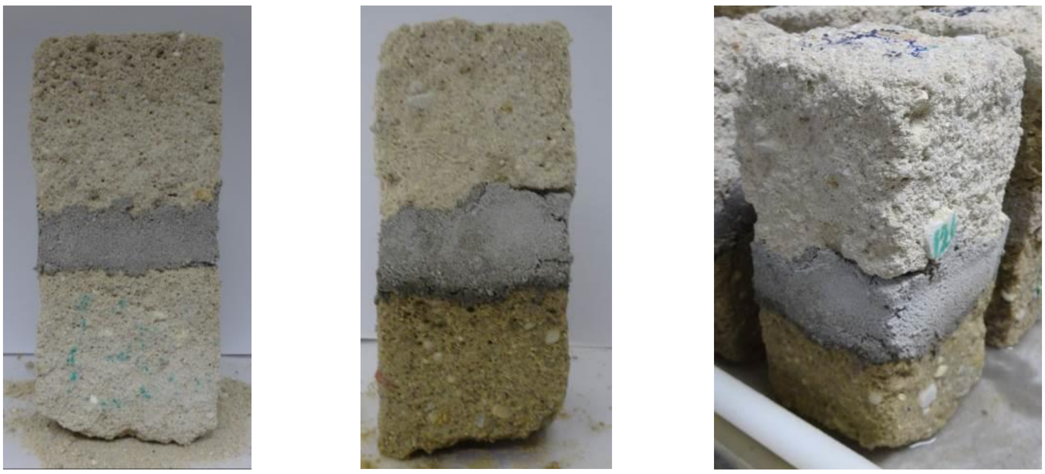
The CiD solution (Figure 5-138) does not show evident manifestation of crystallization above or within the barrier. A transparent film was only observed in some parts of the adobe block below the barrier.

Initial 24 hours 48hours

Figure 5-138 - Results of test – CiD [credits Alice Tavares]

5.6.3.7. The wet front progression with salts of CiDn

The CiDn solution (Figure 5-139) does not show evident manifestation of crystallization in the barrier or below it.



Initial 24 hours 48 hours

Figure 5-139 - Results of test – CiDn [credits Alice Tavares]

5.6.3.8. The wet front progression with salts of CiDnB

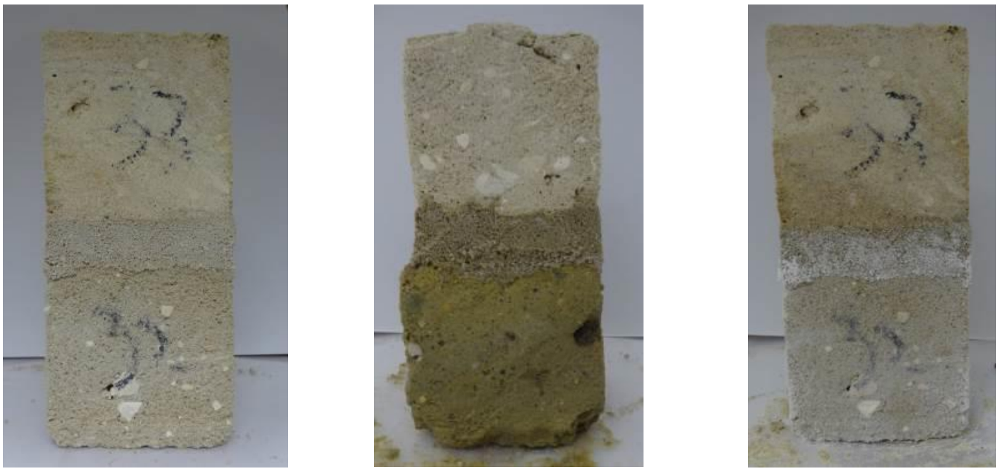
The solution CiDnB (Figure 5-140) does not show evident manifestation of the crystallization in the barrier or below it.

Initial 24 hours 48 hours

Figure 5-140 - Results of test – CiDnB [credits Alice Tavares]

5.6.3.9. The wet front progression with salts of CHDn

The CHDn solution (Figure 5-141) shows a slightly transparent film in the barrier that does not fill the entire surface. The results are not uniform in all of the specimens. The difference is based on the presence of thin white crystallization in the barrier; in some samples, it is through the entire barrier, and in others, it is much more dispersed.

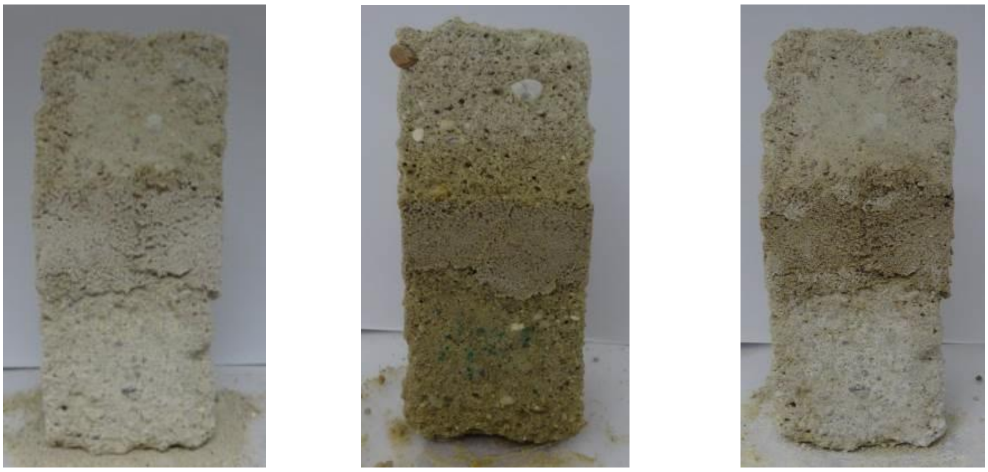


Initial 24 hours 48 hours

Figure 5-141 - Results of test – CHDn [credits Alice Tavares]

5.6.3.10. The wet front progression with salts of CHD

In the CHD solution (Figure 5-142), the wet front reached the top of the specimen. In CHD, a white powder crystallization was observed in the barrier, but it did not have a uniform distribution. A band with a 1.5 cm height was observed immediately above the barrier that formed the same type of powder crystallization.



Initial 24 hours 48 hours

Figure 5-142 - Results of test – CHD [credits Alice Tavares]

5.6.3.11. The wet front progression with salts of CHDt

The CHDt solution (Figure 5-143) presents the same white powder crystallization observed in the previous cases, but only in the barrier. The difference observed is its uniform distribution in the barrier.

Initial 24 hours 48 hours

Figure 5-143 - Results of test – CHDt [credits Alice Tavares]

5.6.3.12. The wet front progression with salts of CHDnB

The CHDnB solution (Figure 5-144) does not show any evidence of crystallization.

Initial 24 hours 48 hours

Figure 5-144 - Results of test – CHDnB [credits Alice Tavares]

5.6.4. Discussion of results of NaCl test

An initial conclusion is that the wet front had a progression delay in almost all of the samples. The specimens did not dismantle or totally collapse at the end of the tests.

The crystallization does not have evident or expressive manifestation. In the Ca solutions, it formed a film immediately above the barrier. A jellied film was formed in the Ci and CiD solutions. The CiDn and CiDnB solutions did not show the presence of this film.

The crystallization is present in all of the solutions with hydraulic lime (CH), but confined mostly to the barrier. The difference between these observations is in the distribution of the powder crystallization, which is more uniform in the CHDn and CHDt solutions, less expressed in CHD, and more confined to the upper interface of the barrier in CH.

5.6.5. Results of Na_2SO_4 tests

5.6.5.1. The wet front progression with salts of CaDn

For all of the samples with salts of Ca solution (Figure 5-145, Figure 5-146), the wet front progression achieved the top of the specimen.

The crystals within the barrier (at 48 hours) are different from the type observed below the barrier. In the barrier, the presence of crystals tends to be uniform; however, during the progress of the test, a second crystallization appeared above the previous, similar to talcum powder, with a progression from inside to outside the first crystallization. The effect of disaggregation above the barrier was evident throughout the wet front, but most immediately at the interface between the barrier and the adobe block.

Initial 24 hours 48 hours

Figure 5-145 - Results of test - Na_2SO_4 [credits Alice Tavares]

24hours 48hours 7 days

Figure 5-146 - Results of test - Na_2SO_4 [credits Alice Tavares]

5.6.5.2. The wet front progression with salts of CH

The wet front rises to the top in almost all of the CH specimens (Figure 5-147). In relation to the manifestation of salts, it was observed that despite the humid barrier, the crystallization was mainly at two levels: in the interface between the barrier and the adobe below and again in the interface of the barrier with the adobe above. After 24 hours, the crystallization is only present at the level below the barrier. At 48 hours, its presence is observed in those two levels, but an increase in the expression of its manifestation was not observed. The area immediately above the barrier presented some disaggregation of the adobe block. Again, the wet front above the barrier was uniformly diffused, a difference in comparison to the other solutions with Ca and Ci.

Initial 48 hours 7 days

Figure 5-147 - Results of test – CH [credits Alice Tavares]

5.6.5.3. The wet front progression with salts of Ci

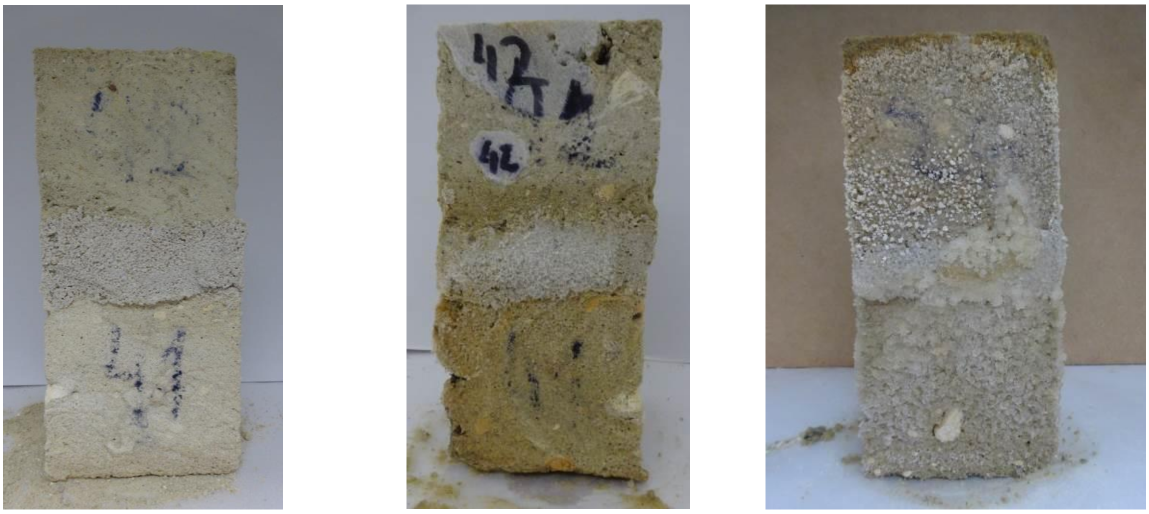
The solution Ci (Figure 5-148) did not present visual evidence of salt crystallization above the barrier. Nevertheless, the barrier was humid, and even after 48 hours, it maintained the same situation despite a high level of capillary absorption. Below the barrier, the crystallization was present at a lower level and the disaggregation was closer to the barrier.

Initial 24 hours 48 hours 72 hours

Figure 5-148 - Results of test – Ci [credits Alice Tavares]

5.6.5.4. The wet front progression with salts of CaDn

In the solution CaDn (Figure 5-149), the type of crystallization in the barrier was not the same as in the other specimens. In some cases, the crystallization forms a second skin with yellow ochre in the barrier; the crystallization continues above the barrier with matt white, above which a second crystallization appears similar to talcum powder and with a progression from inside to outside. This situation is similar to the Ca solution. In the other specimen, a continuous white efflorescence was observed, but not over much of the surface. In this case, the disaggregation of the adobe block below reaches the top of the specimen.

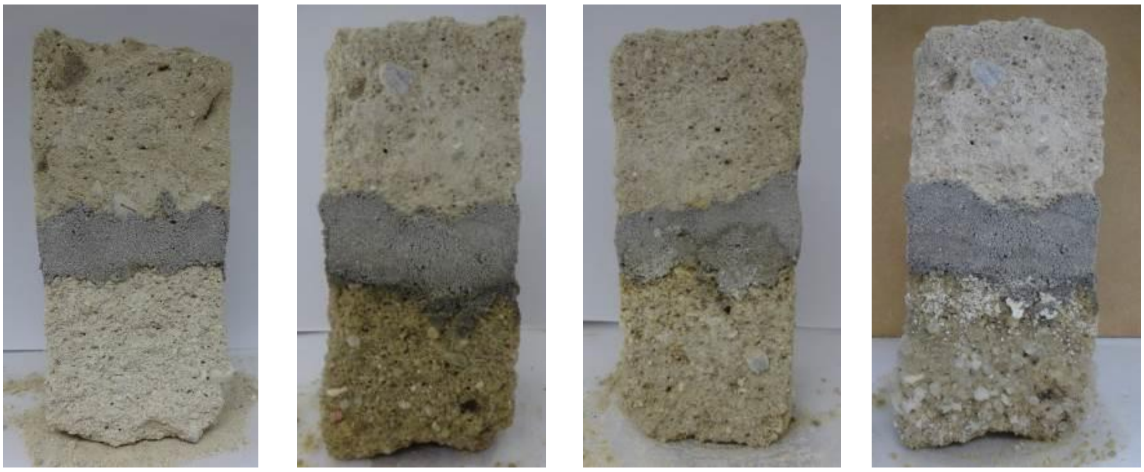


Initial 24 hours 7 days

Figure 5-149 - Results of test – CaDn [credits Alice Tavares]

5.6.5.5. The wet front progression with salts of CiD

The capillary in solution CiD (Figure 5-150) reached the lower level of the barrier at the end of the 24-hour test. The adobe above maintained a dry colour and was apparently not affected by the disaggregation effect of the salts. The same did not happen in the adobe below, where different layers of crystallization and disaggregation were present. Nevertheless, the salts’ effects were not clearly expressed in the part immediately below the barrier, a layer of 2-3 cm in height.

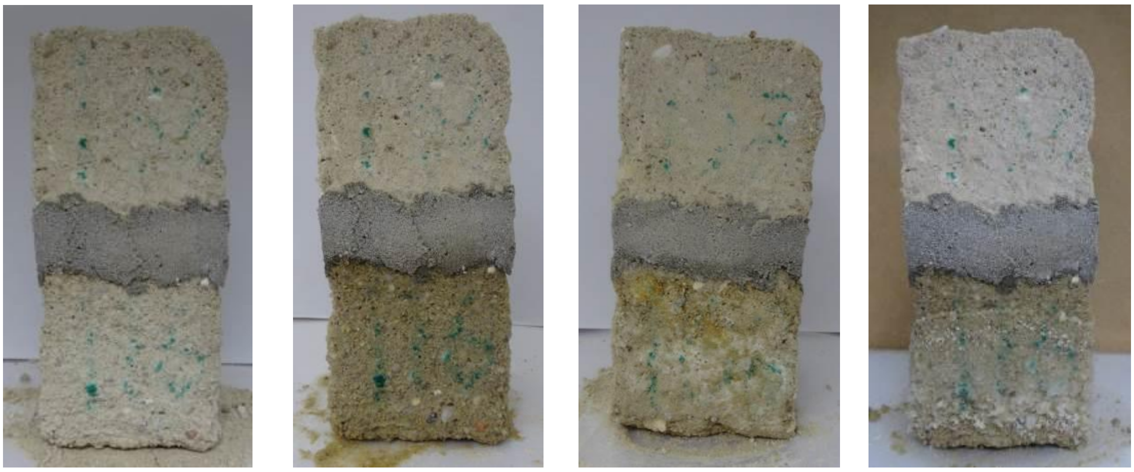


Initial 24 hours 48 hours 7 days

Figure 5-150 - Results of test – CiD [credits Alice Tavares]

5.6.5.6. The wet front progression with salts of CiDn

The solution CiDn (Figure 5-151) presents a similar situation to CiD and Ci; nevertheless, in comparison, the barrier appears to be drier than in the other solutions. The expression of white crystals below the barrier is also less than for the other solutions. The continuous distribution is almost in defined levelled layers.



Initial 24 hours 48 hours 7 days

Figure 5-151 - Results of test – CiDn [credits Alice Tavares]

5.6.5.7. The wet front progression with salts of CiDnB

The solution CiDnB (Figure 5-152) presents a dry barrier throughout the test. The expression of crystallization is only present in the adobe below the barrier. Even in this part of the specimen, the crystallization only reaches 4.5 cm height (the adobe block has an 8 cm height). In some samples, there is a very slight presence of crystallization. The solution appears to be effective as a waterproof barrier and in relation to salts' effects.

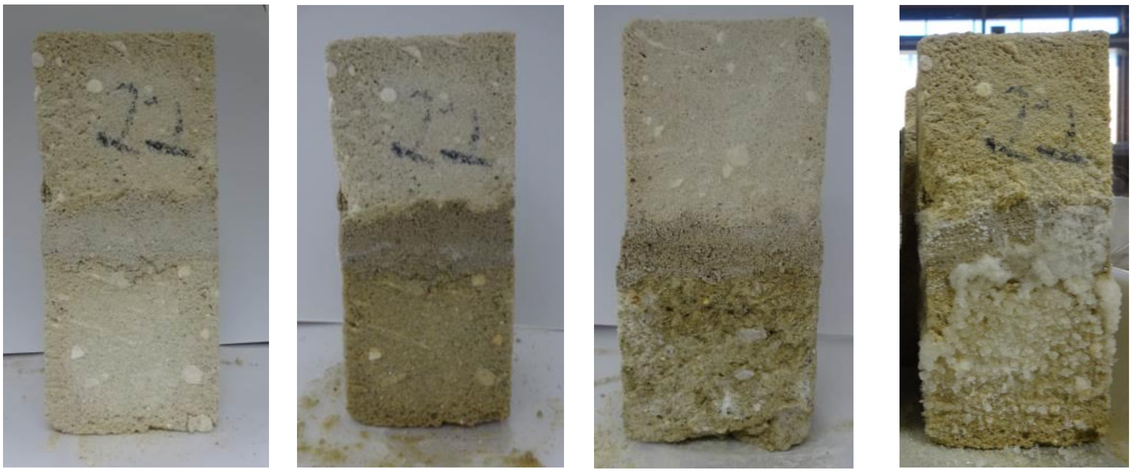
Nevertheless, some disaggregation of the adobe block below the barrier was observed.

Initial	24 hours	48 hours	72 hours

Figure 5-152 - Results of test – CiDnB [credits Alice Tavares]

5.6.5.8. The wet front progression with salts of CHDn

The solution CHDn (Figure 5-153) presents the manifestation of crystallization in the barrier, but mostly in the interface layer above and below the barrier. The disaggregation of the adobe above the barrier is evident, but just to a height of 3.5 cm from the barrier.



Initial	24 hours	48 hours	7 days

Figure 5-153 - Results of test – CHDn [credits Alice Tavares]

5.6.5.9. The wet front progression with salts of CHD

The solution CHD (Figure 5-154) shows the higher manifestation of salts in the below interface of the barrier compared to the solutions with or without not calcined diatomite. The barrier is covered by a layer of matt crystallization, above which the other type of crystallization, similar to talcum powder, appeared. There is a high level of damage above the barrier, with the expressive presence of efflorescence and a disaggregation of the adobe until a level of 3-3.5 cm above the barrier.

Initial 24 hours 48 hours 7 days

Figure 5-154 - Results of test – CHD [credits Alice Tavares]

5.6.5.10. The wet front progression with salts of CHDt

The solution CHDt (Figure 5-155) shows extensive manifestation of crystallization in the below interface of the barrier, similar to talcum powder and again surpassing the previous matt layer of crystallization. Above the barrier, the adobe block presents some disaggregation; however, it is only 2 cm height from the barrier. In this layer, the efflorescence is reduced. The crystallization similar to talcum powder is present below the barrier in one of the specimens.

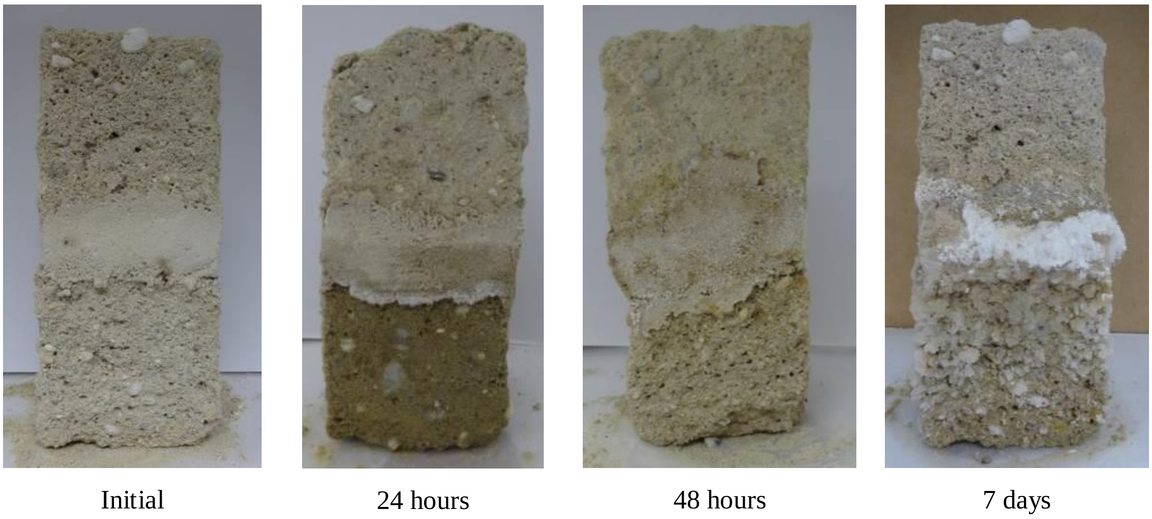


Figure 5-155 - Results of test – CHDt [credits Alice Tavares]

5.6.5.11. The wet front progression with salts of CHDnB

The solution CHDnB (Figure 5-156) shows a dry barrier at the end of the test. There is no evidence of the manifestation of salts above the barrier. The adobe below the barrier presents a transparent crystallization that covers the surface of the adobe until a height of approximately 5 cm.

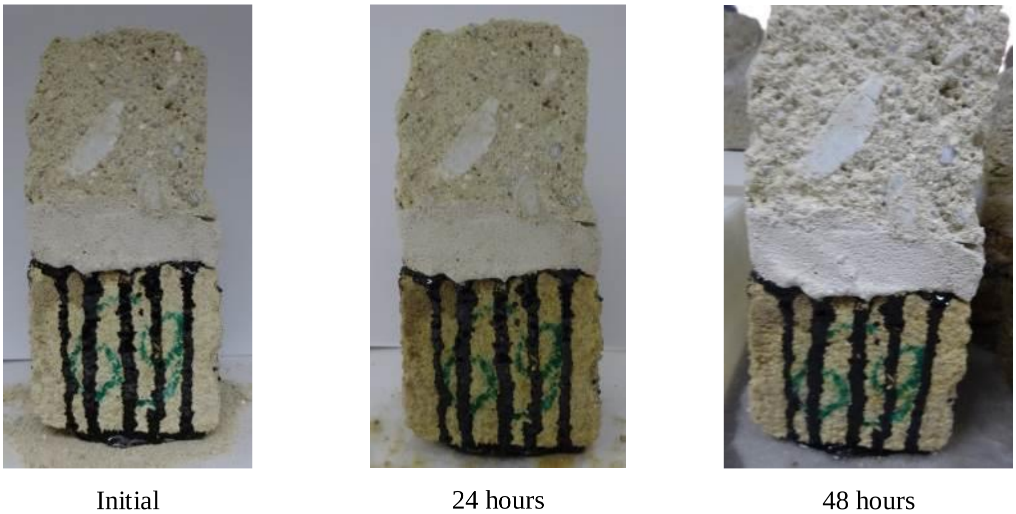


Figure 5-156 - Results of test – CHDnB [credits Alice Tavares]

5.6.6. Discussion of results of the Na2SO4 tests

An initial conclusion is that the wet front had a progression delay in almost all of the samples.

In relation to the solutions with Ci, the conclusions show that the barrier can be effective in blocking the progression of salts. An additional conclusion is that this barrier with diatomite can have a second role in decreasing the progression of crystallization. Whether it can effectively have a double function above and below the barrier is under analysis. The aspect of a drier barrier for the solution with not calcined diatomaceous earth is also under further study.

The addition of not calcined diatomite to solutions of air lime does not show relevant positive results in terms of impeding the progression of salts. Nevertheless, in relation to this solution, further studies need to address calcined diatomite. The results tend to be not uniform with the use of not calcined diatomite.

In relation to the solution with hydraulic lime, the solutions with both calcined and not calcined diatomite did not block the effects of salts. Different manifestations were shown: below the barrier was crystallization with at least two types of crystal, but above the barrier, the manifestation is in the disaggregation of the adobe block.

5.6.7. Conclusions and final comments

Throughout the testing process, none of the specimens was severely damaged or dismantled.

The progression of the wet front decreased in relation to the previous capillary tests without salts in the liquid and considering the same specimens. In some cases, the wet front does not reach the same level as that achieved in the capillary tests. This was the case for CiD in the NaCl tests and CiDn in the Na2SO4 tests. In relation to CiDn, the level at the end of the test (24 hours) was similar to that achieved at 300 minutes in the capillary tests. In general, the wet front did not reach the same level in all of the solutions of hydraulic lime (CH) with diatomite, remaining closer to the level of the barrier. Despite this, in these tests, the wet front passed the barrier in less time in some of the cases.

The first purpose of this research was to confirm the effectiveness of a solution proposed by technicians in the 1940s. Those solutions were implemented at a time of increasing use of cement in mortars. Although cement is known to be incompatible (chemically and mechanically) with adobe, the solution over the short term shows some good effects in blocking rising damp and the presence of salts above the barrier.

The results show a selective effect when barriers with diatomite are used. It appears that the use of diatomite can provide benefits for one type of salt but not for the other. This conclusion is in line with some information from USA enterprises responsible for improving soils for agriculture.

The manifestation of salts was more evident and expressive in the case of Na2SO4 than in NaCl, where the damage to the adobe blocks and barrier appeared to be much lower. Another conclusion is that for NaCl tests, most of the manifestations of crystallization are present in the barrier. To the contrary, in relation to Na2SO4, these manifestations are confined to the barrier area and present a greater variety of manifestations.

The solutions with crude oil substitute also show that the rising damp and the manifestation of salts do not pass the barrier. These solutions appear to be the most effective. Nevertheless, the solution is debatable in terms of its environmental impact.

Another conclusion from these tests is that the different forms of crystallization do not manifest at the same time. A white thin crystallization only appears in a second moment, surpassing the previous layer of matt crystallization, moving from the inside to the outside. This occurred in some of the solutions with air lime and hydraulic lime.

In relation to the solutions with hydraulic lime, a change in the ratio between binder and aggregate are shown to have slightly improved behaviour in relation to the progression of salt effects (Na2 SO4 salt). It was shown that although crystallization was evident in the below level of the barrier, it had fewer effects above the barrier. In addition, a decreased presence of crystallization was shown in the rest of the barrier.

A main conclusion is that the addition of diatomite improves the barrier’s capacity against the progression of salts in most of the cases.

The tests also demonstrate that the type of crystallization below and above the barrier is not the same in many of the cases. In some cases, the difference is between the type of crystallization manifested in the barrier compared to that in the rest of the specimen. This shows that the barrier has an effect on this process.

Although in several of the cases, the addition of calcined diatomite generated a more uniform and improved behaviour for the barrier and reduced the results of salts effects, the non calcined diatomite showed better results in some solutions in relation to the previous D.

Ongoing research will provide conclusions about the possibility of controlling these characteristics and using them in a beneficial way.

5.7. The application of this research to the public awareness of maintenance and conservation

One of the most noted measures in the international reports is the preparation of manuals that can provide guidelines for the public in general and for the owners of built heritage. These guidelines are important measures for protecting vernacular heritage, in which traditional techniques have been lost. There are a few international applications already, where municipalities have combined rehabilitating the historic centre or agricultural settlements with giving technical support to the owners. In this matter, the Portuguese case of Guimarães can be emphasized; despite the some differences and that the buildings are constructed of stone masonry, it is a recognized case of success that achieved classification as a World Heritage Site. Another interesting case is Bath, an ancient Roman settlement in England. The most interesting topic is the great awareness that the public has of the preservation and protection of its own heritage. This awareness also shows continuous work by a municipality to achieve a notable level of harmonization between the new and the old, between history and modern life. It is a commitment that is assumed to be shared by everyone.

Other similar studies can also be noted, such as the case of Japan (JENESYS 2010; Tavares A et al 2013c) or the case of Alberobello in Italy. However, these are not cases of adobe construction; they represent impressive vernacular architecture that is recognized mostly because of the construction system and the amazing form that it impresses to whole buildings.

The specific case of traditional adobe construction in Cyprus, where a programme for the conservation of the old buildings was carried out a few years ago, should also be noted. Although, in the present, the population struggles with an economic crisis, that programme was successful in improving the living conditions and maintaining much of the traditional construction. The other case with the support of research is in Sardinia, with the work of Achenza M (2008), who prepared a conservation manual as a measure to protect the traditional adobe construction and promote its conservation.

In the beginning of this PhD research in 2011, a rehabilitation /conservation manual was proposed with the support of Inovadomus and the University of Aveiro in 2011. This manual is still presently online:

(http://www.tecsat.com.pt/inovadomus/fh/images/documentos/article/5/MANUAL_INOVADOMUS.pdf) and represents a first attempt to give information to owners, technicians, politicians and enterprises for protecting regional heritage.

Another step was the preparation and publication of a maintenance manual because the first measure to protect heritage is to use and to maintain it. For this reason, the proposal of the Vista Alegre Atlantis factory to give some information to the owners of the region for the preservation of this type of building was welcome during this research. A manual that could be accessible to the population in terms of both the language used and the price was prepared. It was published by editor in 2014. A few concepts that this research aims to contribute are the awareness of the cultural value of traditional adobe construction and the need to protect it. This maintenance manual is published by Publindustria and accessible to the public in several libraries. Both manuals (Figure 5-157) were concluded during this thesis, as co-author of both are open to outcomes that improve them; the most important point is not the research itself, it is what we can achieve to positively contribute to the balance of protection and conservation of built heritage.

Figure 5-157 - Publications of Manuals [credits Alice Tavares]

5.8. Conclusions of Chapter 5

To understand specifically what measures were noted to overcome the lack of protection and conservation of built heritage, only the data from ICOMOS and UNESCO reports about this subject were selected (from 35 countries over the period from 2000 to 2014), from the following countries [66 until 99]: Australia, Bolivia, Bulgaria, Canada, China, Colombia, Côte d'Ivoire, Cyprus, Cuba, Czechoslovakia, Ecuador, Egypt, France, Georgia, Italy, Iran, Japan, Lithuania, Macedonia, Mali, Malta, Myanmar, Nepal, New Zealand, Panama, Peru, Republic of Slovenia, Romania, Slovakia, Turkey, Uganda, UK, USA, Venezuela, Yemen and Yugoslavia.

The reports, instead of the general guidelines, from both international organisations were analysed because the problems analysed in chapter two showed a discrepancy between protection and conservation theory with respect to heritage sites. For this reason, this study prefers to analyse the noted solutions for the problems detected in the field. This analysis will focus on civil architecture/vernacular architecture to be more associated with the theme of this research: strategies for conserving adobe buildings.

From the topics analysed, it is possible to see that concerns about conservation philosophy are almost absent from the reports. The same pattern is observed monitoring and evaluation issues; there are very few recommendations on these subjects. All of the other topics, including strategy, planning and implementation, were the most discussed in the reports with some suggestions in this field.

This research also focuses on what can be considered recent heritage, due to an identified gap in research about this period in the region. The adobe buildings built in the 1940-1956 period reveal two distinct phases, mainly in Aveiro, where an experimental phase of organizational and aesthetic types was implemented by technical designers, architects and non-architects (mainly linked to the porcelain factory of Vista Alegre). This experimentation includes the references already produced for the Workers Quarter of Vista Alegre but goes far beyond just these models, creating models that are easily distinguished from the others and in some cases were repeated by other technicians in the region.

The fact that the company has its own body of engineers and other technicians that was responsible for new construction, the maintenance and rehabilitation of buildings, and the processes that recycled building materials and controlled the quality of the intervention, assured the company of the potential of adobe and taught them aspects of controlling its preservation. Furthermore, the connection facilitated architectural services in Lisbon Port, which could be the basis for some solutions; it was common for architects to send pencil sketches of projects, which were then adapted to constructing adobe systems and for the functions required and the existing conditions.

All of these professionals more broadly maintain the adobe technique, both for buildings in Vista Alegre and the county, and with great connection to owners with greater economic capacities, such as industrial fishers, merchant marine captains, medical professionals, and wealthy farmers. However, their actions are developed not only in areas with land and buildings but also the areas from where the workers lived, in the vicinity of VA Neighbourhood, the area connecting to the port of Aveiro, and fishing areas, among others. These technicians will promote an approach to living space outside the traditional system before architects become involved.

The fact that the areas of expansion in Ílhavo in the years considered here have been mainly associated with agriculture, not requiring special design conditions and being a more conservative activity, favoured continuing the use of adobe. This association with agriculture is an important reason for maintaining the use of adobe, the application of which decreased in the central urban areas but grew in the areas with new development. In addition, it is also one of the reasons for the return to traditional buildings after World War II, significantly reducing the number of buildings in the Modernist period. A return to the tradition of building with adobe, though following the Modern movement line that favoured using brick, curiously favoured using adobe foundations - the last adobe element out of the building system.

The causes for the declining use of adobe, rather than the increasing use of reinforced concrete in this region pressuring the ceramic industry, were changes at the level of the technicians and engineers involved in the territory. These technicians and engineers did not have much knowledge about the building systems and regulatory changes, particularly after the implementation of the development plans that were responsible for the gradual disappearance of the technique.

In the built heritage, adobe has found expression in various regions of the world, being very rich in terms of cultural diversity, and revealing a deep connection to social and natural environments. This study addressed its final implementation stage in Portugal, particularly the period connected to the 2nd World War. This phase was very interesting and multifaceted, and its dialogue between vernacular architecture and classical architecture revealed many thoughts, questions and debates that characterised the time, including among architects, technicians and society in general.

This research showed that there is not a large difference between the performances of the different approaches, which means that thermal insulation from the inside to outside is needed to fulfil the thermal comfort requirements of the present regulations, namely in the winter period. These technical facts indicate that all of the solutions have the same problem, which is the need to be heated in the winter period. Nevertheless, the mixed solution E, adobe at the first floor and brick masonry (a double leaf wall) seems to have the better behaviour.

In a rehabilitation intervention concerning adobe constructions or old brick masonry buildings, a thermal behaviour assessment is crucial to propose adequate thermal insulation solutions to respond to the expected comfort and energy efficiency requirements.

This research has also highlighted that there is no reason in terms of the thermal behaviour to demolish adobe houses but that they should be rehabilitated to take advantage of their thermal inertia. Taking into account the sustainable character of the materials in adobe construction, this research provides relevant data to use in practice and to compare with other scientific studies of adobe or rammed-earth issues.

The research work presented here, and the research that is intended to develop, is extremely important for future rehabilitation interventions for these types of buildings, a step towards sustainable urban plans. This work has contributed to the maintenance of adobe built heritage and highlights the importance of its full characterization, including its needs for thermal performance assessments and interventions.

The results show a selective effect when using barriers with diatomite. It seems that the use of diatomite can benefit from one type of salt but not from another. This conclusion is in line with some information from American enterprises responsible for the improvements of soils for agriculture.

Solutions using petroleum substitutes also show that rising dampness and the inclusion of salts do not pass the barrier. In this sense, the petroleum-substitute approach seems to be the most effective. Nevertheless, its environmental impact should be discussed further.

Another conclusion from these tests is that different forms of crystallization do not manifest at the same time. There is a white thin crystallization that only appears secondarily, surpassing the previous layer of the matte crystallization with a movement from the inside to the outside. This phenomenon occurred in some of the solutions with air lime and hydraulic lime.

A main conclusion is that the addition of diatomite improves the barrier capacity against the progression of salts in most of the cases.

Through the tests, it can also be noted that the types of crystallization below and above the barrier are not the same in many of the cases. Sometimes, the difference is between the type of manifestation of crystallization in the barrier compared with in the rest of the specimen. This behaviour shows that the barrier has an effect on this process.

Although in several of the cases, the addition of calcined diatomite resulted in a more uniform behaviour of the barrier and better results for the effects of salts, the non-calcined diatomite showed better results in some solutions in relation to the previous configuration D. Ongoing research will study the possibility of controlling these characteristics and using them in a beneficial way.

In the beginning of the present PhD research, a rehabilitation /conservation manual was proposed with the support of Inovadomus and the University of Aveiro in 2011. This manual is online and represents a first attempt to give information to owners, technicians, politicians and enterprises for protecting regional heritage.

Another step was the preparation and publication of a maintenance manual because the first measure to protect a heritage is to use and to maintain it. For this reason, the proposal of the Vista Alegre Atlantis factory to give some information to the owners of the region for the preservation of this type of buildings was welcome during this research. A manual that could be accessible to the population in terms of language used and in terms of price was prepared. It was published by Publindústria Editor in 2014. A few concepts that this research aims to contribute are the awareness of the cultural value of traditional adobe construction and the need to protect it.

6. CONCLUSIONS AND FUTURE WORKS

6.1. Introduction

The purpose of this chapter is to focus on the overall results of this investigation. Chapter two describes the objective of the need for awareness of the cultural value of traditional construction systems and the risks of losing the traditional built heritage in a wider environment of risk. Chapter three describes the knowledge of the evolution of adobe construction system as a basis for enhancing this heritage and to support future interventions. Chapter four identifies the main defects of the traditional construction systems that should be considered for establishing an integrated conservation strategy framework. Chapter five provides strategies concerning the adobe heritage conservation framework and particular main gaps that need continuous research, it also present research findings. This final chapter addresses the main conclusions of the above-mentioned research aims.

6.2. Integrated Conservation Strategy proposal

The present research proposes the following scheme to establish the levels of need to maintain a cultural value as a main objective of an integrated conservation strategy (ICS) and agreeing with many of the English Heritage principles of Conservation (Drury P, McPherson A 2008).

The ICS tree proposal consists of a stratified distribution of the levels of approach for the built heritage, giving major importance to cultural resources/heritage. Therefore, all of the actions above this level should be related to maintenance (M) and cultural value protection (CVP). Both are important issues for the cultural sustainability of built heritage (Tavares A et al. 2013c). As observed, these factors are considered in the first stage of an approach and are much more important than all of the other types of intervention. Nevertheless, a proactive, well-planned attitude should underline both. The second stage should be conservation, considering that it has the previous actions (M) at its base; again, it is proposed as an equal level of importance in terms of the impact assessment for the measures proposed during the planning.

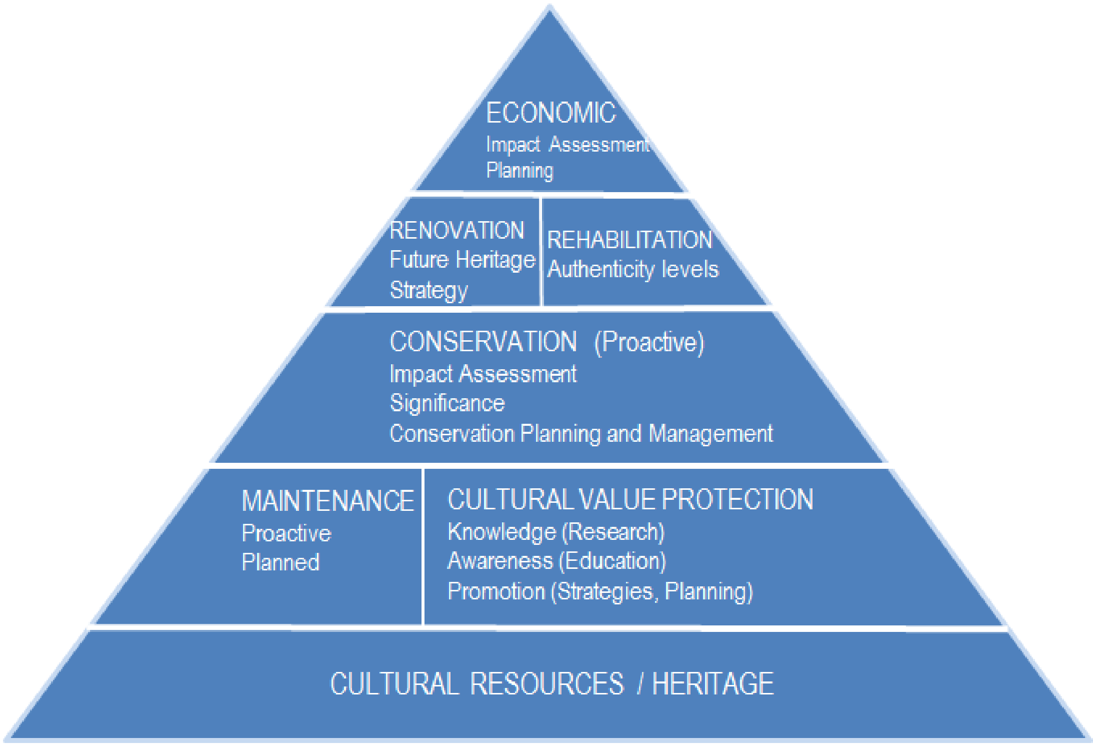


Table 6.1 – Levels to balance the insertion of an Integrated approach of Conservation (ICS)

6.2.1. Research objective of awareness of the cultural value of traditional construction systems and the risks of loss (chapter two)

The construction system is the skeleton of the building framework and a common basis of conception for not only architecture and engineering but also other conservation specialities. Understanding the specific character of a traditional construction system in comparison with the present and more technologically advanced idea of a construction system can be one of the reasons for failure. The lack of awareness of the specific conservation needs for traditional construction systems has led to legislation, regulations and practices of intervention that are incompatible at many levels (material, physically, aesthetically, etc.), a reason for the current dramatic loss of this heritage in many regions of the world. The traditional systems of construction represent a relevant cultural value that can be common to several cultures, as can be observed with respect to mixed construction systems with timber. An example of this effect is the disseminated similar solution of the corner in traditional construction systems of earthquake-prone regions. Nevertheless, with respect to the adobe construction studied in this research, the difficulties come from the lack of public and political, awareness of the cultural value of this ancient technique; the lack of national regulations that establish the framework of conservation and rehabilitation theory to follow, promoting the preservation of high levels of authenticity; the lack of knowledge of practitioners and builders; the obstructive action of taxes that discourage the rehabilitation of this type of buildings and their transactions; and the lack of an effective framework of promotion and education for the public in general.

This investigation has identified several reasons for failure in built heritage conservation and protection. The most common cause identified is the lack of a long-term conservation strategy, which entails the absence of guidelines, regulations and a recognized framework defining the responsibilities and role of each ‘actor’ involved. This framework involves all of the levels of approach: international, national, regional and local. Several other causes were identified:

1. Lack of appropriate plans and management.

2. Lack of planned education about heritage awareness and continuing protection in the long term.

3. Lack of control of investment – the measures should anticipate the stress imposed on heritage sites and be clear in terms of restrictions or incentives.

4. Insufficient technical skills at all levels - maintenance, conservation and rehabilitation, and planning.

5. Communication of research – increasing its connection with the measures in the field and the establishment of intervention strategies at all levels.

Unbalanced urban development is an effect of the lack of a strategic plan and management with the critical capacity to promptly act if necessary. This development includes conservation strategies but also their absence. Politics play a significant role in delaying and blocking conservation strategies, including education strategies for raising awareness of the value and protection of the heritage. The last two issues addressed are directly linked with the research field. Both issues reveal that research develops work only for itself without many concerns regarding the active or proactive involvement in the field. A better link between these two sectors of conservation is necessary.

6.2.2. Research objective of knowledge of the evolution of the adobe construction as a basis for the enhancement of this heritage (chapter three)

Assessing the significance of the adobe built heritage is based on understanding the characteristics of the construction system, its evolution and basis of influence in different fields and its multicultural value. The investigation also confirmed the need to understand how this heritage was built, with which actors and with which social, historical or economic environment. The background of this heritage also gives information about its vulnerabilities and reasons for its loss, but also the knowledge support for its protection.

6.2.3. Research objective: identification of the main defects of the construction system (chapter four)

Through analysing the *in situ* surveys data, it was possible to address the main problems that can compromise the preservation of adobe built heritage. Behind the several assessed defects is the lack of maintenance practices, the frequent change of ownership that has led to the abandonment or disuse of the buildings, the lack of attempted repairs, and the lack of conservation or rehabilitation. However, it is important to notice that all of these main issues have their origins in the lack of proactive initiatives of protection and conservation.

6.2.4. Research objective: strategies concerning the adobe heritage conservation framework and particular main gaps that need continuity of research (chapter five)

The last approach regarding a preventive and proactive conservation strategy needs to establish a common framework of conservation principles, priority areas of action, and the establishment of measures to prevent collapses and continuous decay (even in disused buildings). In fact, the development of a strategy involves different stages of approach targeted toward the different actors of the network. Following this orientation, this investigation emphasizes and presents three specific sectors that need to be studied: the historical interaction between traditional construction systems and the architecture of their authors, the comfort issue, and the main ancient waterproof barriers with natural materials (diatomaceous earth) to surpass the main non-structural defect of rising damp.

6.3. Summary of main conclusions of the thesis

This research considers the following as its main conclusions: the debate involving the interaction between understanding the particular character of traditional construction versus the wide range of techniques available, need an exigent and accurate sense on the intervention strategy.

The lack of knowledge about traditional construction systems, the difficulty of controlling their structural performance and the exact characterisation of their state of conservation must not be an obstacle to their preservation. This implies that significant background knowledge encompassing multidisciplinary approaches for interventions in vernacular construction systems is necessary. The compatibility of definitions, the knowledge achieved through written ancient sources, the identification and understanding of the links of culture or technique exchange are relevant issues to include in the research of traditional construction techniques. The link between the evolutions of European traditional construction with the Asian antique construction is recognizable, namely the one involving mixed systems with timber structure. The comparative study of some historic and vernacular construction systems, from different seismic prone regions, shows the relevance given in the construction to the connections between perpendicular walls to improve the global capacity. This is an area of research that needs further developments, mostly involving the examples with seismic resilience. The ancient documental resources are a highly valuable issue to include in the analyses of the ancient constructions systems. Although the existent buildings are a main resource of information, the multicultural missing link can be achieved in many of the treatises and books of practices. This research pointed out just one of the examples – the solution used in the corners – that is transversal to many cultures and show that the awareness of the same construction limitation can lead to a similar solution. It is also necessary understand some of the main differences in the categories of the construction systems and that the old solutions present specific characteristics. This is also the basis to understand why the traditional construction systems cannot be under the same roles as the present technological solutions, they belong to a different field. Although the adobe construction system is present in almost all continents, the difficulties in its protection is similar than the traditional mixed systems with timber or even with stone masonry.

The causes that are responsible for the loss of the traditional heritage were analysed through the ICOMOS reports of more than 35 countries correspondent to the period between 2000 and 2014. It was given a special attention to the sectors of: monumental and public buildings; historic urban centres; agro-industrial settlements; vernacular architecture and the new heritage of Modern Movement buildings. This is the main sectors that the adobe construction was also applied; despite in relation to Modernist buildings it was mostly observed in a very first stage of the architectural Movement in Portugal. Nevertheless, it is interesting to understand the problems common to other traditional construction systems, in a globalized world, the awareness of the causes of disappearing of this heritage should also have a wider focus.

From the resume of causes of the subchapter 2.6 – Risks of loss of cultural value – can be concluded that there are five transversal main causes to all of the sectors, which are:

1. Lack of appropriated plans and management.

2. Lack of planned Education - for heritage awareness and protection in long term and continues.

3. Lack of control of investment – the measures should anticipate the stress imposed to heritage places and be clear in terms of restrictions or incentives.

4. Insufficient technical skills at all levels -of the maintenance, conservation and rehabilitation, planning;

5. Communication of research – increasing their link with the measures in the field and in the establishment of strategies of intervention at all levels.

In all these causes it was very frequent the mention to aspects that could be avoided if a proactive attitude was perceived and an effective co-ordination at all levels, from the governments to regional entities and involving the owners. The inertia to take preventive actions reveals three other problems:

a) A public opinion less developed and aware of the problems, with initiative to share the planning decisions and with capacity to pressure the political decision. Although in some cases is not allowed to do so;

b) The principle of minimal intervention is rarely promoted in the context of renovation or reconstruction procedure on existing buildings, consequently the understanding of the problem involves always a huge amount of resources that are not available.

c) Incapacity of the authorities/entities, namely politicians to prepare sustainable and adequate measures (long-term strategy) that go behind the period of their permanence in charge. This also involves a lack of evaluation of the present situation, the monitoring of the programs for attempted correction measures and a better distribution of resources.

Finally, it should be emphasized that was also several times identified problems in the conservationist approach, for the preservation of the authenticity the work not always is undertaken by adequately trained personnel. The same with respect to companies and contractors working in conservation projects, that not include technical staff, adequately trained to act as respondents for the conservation experts, as well as workers and crafts persons appropriately trained to accomplish the work. A multidisciplinary approach with people from different backgrounds is an adequate approach; however clustered actions lead to negative results, in particular when cultural heritage is used as an opportunistic resource.

At least three key reasons to study traditional construction techniques today can be addressed by researchers to help the protection of the cultural value:

- To give accurate guidelines for the Protection and preservation of this heritage based on research and laboratory tests, increasing the communication of his knowledge to technicians who work in the field;
- Dissemination of the knowledge that supports multicultural values awareness based on an understanding of the links between traditional construction methods (which can lead to an interesting debate on identity);
- To propose guidelines for adequate maintenance measures, compatible interventions in terms of materials, techniques (conservation or rehabilitation) and strategies that can guarantee the future use of buildings with high cultural value.

This thesis presents an original research of the evolution of the adobe construction in the region of Aveiro. For a wider understanding it was used data from the Porto region a main influence to Aveiro district. Furthermore, it was prepared resume tables that can help in the assessment of the buildings and it is divided in the main components of the construction.

All the described problems observed in the existent earthen constructions seem to be easily to understand and to prevent. However, in the practice it was recorded a high number of problems, some of them due to the action of technicians, of the owners with incorrect interventions or even a sequence of construction regulations that were not adapted to this traditional system of construction. It is interesting to see that some of the ancient treatises (from the 15th century) already have pointed some of the situations to avoid the defects and to promote the durability of the construction. Nevertheless, in some moment this knowledge did not pass in the communication through generations of builders or technicians or even it was not sufficiently widespread. It will be pointed out some of these concerns that could be a general guideline to prevent the problems observed in the adobe construction. A relevant example is the Alberti treatise and some others with seismic concerns (Vivenzio 1787 and Milizia 1813) which are interesting for this reflexion, although they do not focus adobe construction specifically. Nevertheless, they tried to present a set of good practices, concerning the different components of the construction and how to avoid potential vulnerabilities. In this sense, Alberti highlighted several situations to prevent defects on the construction and emphasized the interest of the observation in situ of the ancient buildings as a resource of important information and learning. In these final remarks it will be pointed out some of these reflexions following the structure of this chapter: foundations, walls and openings, floors and roofs.

One of the most important aspects for the durability of adobe construction is the ventilation of the basis of the construction. Again, it is stated in the Alberti's books the advice on ventilation of basements and foundations to prevent rotting (Rykwert J et al. 1996).

At the level of the roofs the most problems observed had as principal cause a lack of maintenance of promptly repairs, which are responsible for the decay of the roof structure the most of the times. Although in some cases, incorrect interventions play a significant role in the decreasing of load capacity of those structures or in the maintenance of their stability. This is the case of the demolition of interior walls that play a secondary role in the support of the roof structures or are connected with them or the cut of principal elements of the roof trusses, leading to the pointed out defects. In relation to the fire problem, it is a concern observed near industrial areas in the adobe region as in many other urban places since the industrialization.

Finally, it should be said that the prevention of decay and damage due to extraordinary events (as earthquakes, storms or wind) anticipating these situations is a necessary strategy to minimize the cost of repair and to protect the buildings from being lost forever.

To understand specifically what measures were pointed out to surpass of lack of protection and conservation of the built heritage it was just selected the data from reports of ICOMOS and UNESCO about this subjected (from 35 countries involving the period from 2000 to 2014), from the following countries [66 until 99]: Australia, Bolivia, Bulgaria, Canada, China, Colombia, Côte d'Ivoire, Cyprus, Cuba, Czechoslovakia, Ecuador, Egypt, France, Georgia, Italy, Iran, Japan, Lithuania, Macedonia, Mali, Malta, Myanmar, Nepal, New Zealand, Panama, Peru, Republic of Slovenia, Romania, Slovakia, Turkey, Uganda, UK, USA, Venezuela, Yemen and Yugoslavia.

The option of analysing reports instead of general guidelines of both international organisations is because the problems analysed in chapter two showed a discrepancy between protection and conservation theory with the situation on heritage sites. For this reason, this study prefers to analyse the pointed out solutions for the problems detected in the field. This analysis will focus in the civil architecture/vernacular architecture due to be more associated with the case study of this research: Conservation of adobe buildings strategies.

From the topics analysis it is possible to see that concerns with Conservation philosophy are almost absence from the reports, the same happens with the Monitoring and evaluation issues, there is a very few recommendations on these subjects. All the other topics of Strategy, Planning and Implementation were the most discussed in the reports with some suggestions in this field.

This research focuses also the attention in what can be considered the recent heritage, due to an identified gap of research about this period in the region. The adobe building built in the 1940-1956 period reveals two distinct phases mainly in Aveiro, where an experimental phase of organizational and aesthetic types are implemented by technical designers architects and non-architects (mainly linked to the Porcelain Factory of Vista Alegre). This experimentation includes references already produced for the Workers Quarter Vista Alegre, but goes far beyond just these models, creating models that easily distinguished from the others and in some cases will be repeated by other technicians of the region.

The fact that the company has its own body of engineers and other technicians who was responsible for new construction, maintenance and rehabilitation of buildings, a process that used the recycling of building materials and controlled the quality of the intervention assured them the experience to know adobe's potential and know the aspects to control in its preservation. Furthermore, the connection facilitated architectural services both Lisbon Port, can be the basis for some solutions, as was common sending pencil sketches of projects by architects, which are then adapted to the constructive adobe system and functions required and existing conditions.

Are these professionals more broadly maintain the adobe technique, both for buildings in Vista Alegre or to the county and with great connection to the owners with greater economic capacity, such as industrial fishing, captains of the merchant marine, medical, wealthy farmers etc. However, not exclusive to, since their action is developed especially in areas where they have land and buildings, but also the areas from where the workers lived, or in the vicinity of VA Neighbourhood, either in the connection area to the port of Aveiro and fishing, among others. These technicians will be those who will promote before the entry of the architects an approach to living space outside the traditional system.

The fact that the areas of expansion in Ílhavo in the years have been mainly associated with agriculture, not requiring special design conditions and on the other hand is a more conservative activity, favored the continuation of adobe. This will be one of the important reasons for maintaining the adobe, the application of which decreases in the central urban areas but grows in the areas of new development. In addition, it is also one of the reasons for the fact that after World 2ªGuerra to turn the traditional types, significantly reducing the buildings of Modernist trial period. A return to the roots in the built of adobe, following the Modern Movement line already with the brick, though as has been said, curiously adobe foundations - the last adobe element out of the building system.

Regarding the decline in the use of adobe, rather than the cause of the increasing use of reinforced concrete in this region will be the pressure of the ceramic industries, changes at the level of technicians and engineers involved in the territory and whose education had not much knowledge about the building system and regulatory changes, particularly after the implementation of the Development Plans that will be responsible for this gradual disappearance of the technique.

The heritage of vernacular architecture adobe has as found expression in various regions of the world, being very rich in terms of cultural diversity, revealing a deep connection to the social and natural environment where you are. This study addressed its final implementation stage in Portugal, particularly the period more connected to the 2nd World War, a very interesting phase, multifaceted, whose dialogue between vernacular architecture and classical architecture reveal a lot of thought, questions and debate that characterised the time, including architects, technicians and society in general.

This research showed that there is not a big difference between the performances of the different solution, which means that thermal insulation from the inside to outside is needed to fulfil the thermal comfort requirements of the present regulation, namely in the winter period. These technical facts indicate that all the solutions have the same kind of problems, which is need to be heated in the winter period. Nevertheless the mixed solution E, adobe at first floor and brick masonry (double leaf wall) seems to have the better behaviour.

In a rehabilitation intervention concerning adobe constructions or old brick masonry buildings the thermal behaviour assessment is crucial to propose adequate thermal insulation solutions to respond to the expected comfort and energy efficiency requirements.

This research has also highlighted that there is no reasons in terms of thermal behaviour to demolish the adobe houses that should be rehabilitated to take advantage of their thermal inertia. Taking into account the sustainable character of the materials in adobe construction, this research provide relevant data to use in the practise and to compare with other scientific research of adobe or rammed earth issues.

The research work presented in here and the one that is intended to develop is extremely important for future rehabilitation interventions of these types of buildings, a step towards the sustainable urban plans. This work has contributed to the maintenance of adobe built heritage and highlights the importance of full characterization of it including their needs of thermal performance assessment and intervention.

This research also addressed the problem of waterproof barriers from the 1940's and 1950's. The Main conclusions are the following.

The solutions that can be assumed as waterproof barriers are the both solutions with crude substitute – CiDnB and CHDnB.

The solutions which wet front did not pass above the barrier are CiDn and CiD.

The solutions with fewer results surpassing the barrier within 24 hours are: Ci (in half of the samples); CiDn (none sample was surpassed); CiD (none sample was surpassed); CHDt (only 2 samples did not have barrier surpass).

The solutions which wet front reached the top level of the specimen are: Ca (almost all of them) and CaDn (half of them).

After all the process of test none of the specimens was severely damaged or dismantled (even after the 48 hours).

The progression of the wet front decreased in relation to the previous capillary tests without salts in the liquid, considering the same specimens. In some cases the wet front does not reach the same level as achieved in the capillary tests. This was the case of CiD in NaCl tests or CiDn in Na2SO4 tests. In relation to CiDn the level in the end of the test (24 hours) was the similar to the achieved at 300 minutes in the capillary tests. In general the wet front did not reach the same level in all the solutions of hydraulic lime (CH) with diatomite, remained more near the level of the barrier. Despite of this, in this tests the wet front pass in less time the barrier in some of the cases.

The conclusions of this research had the first purpose to confirm the effectiveness of the solution proposed by technicians in the 1940's. Those solutions were implemented in a moment of increased use of cement in the mortars. Although the cement is known as incompatible (chemically and mechanically) with adobe the solution in a short-term show some good effect in relation to block rising damp and salts presence above the barrier.

The results show a selective effect when used barriers with diatomite. It seems that the use of diatomite can benefit for one type of salt but not for the other. This conclusion is in line with some information of USA enterprises responsible for the improvements of soils for agriculture.

The salts manifestation was more evident and expressive in the case of Na2SO4 than in relation to NaCl where the damages to the adobe blocks or barrier seemed to be much lesser. Other conclusion is that in relation to NaCl tests the barrier is where it is present the most part of the manifestations of crystallization. On the contrary in relation to Na2SO4 these manifestations are confined to the barrier area present a greater variety of salts manifestations.

The solutions with crude oil substitute show also that the rising damp and the manifestation of salts do not pass the barrier. In this sense, seems to be the most effective. Nevertheless, it is a discussable solution in terms of its environmental impact.

Another conclusion from these tests is that the manifestation of the different crystallization does not process at the same time. There is a white thin crystallization that only appears in a second moment, surpassing the previous layer of the matt crystallization with o movement from inside to outside. This happened in some of the solutions with air lime and hydraulic lime.

In relation to the solutions with hydraulic lime it is show that a change in the ratio between binder and aggregate can have a slightly increased good behaviour in relation to the progression of salts effect (Na2 SO4 salt). It was shown that despite the crystallization was evident in the below level of the barrier, it had less effects above the barrier, besides the fact that in the rest of the barrier it was shown a decrease of presence of crystallization.

A main conclusion is that the addition of diatomite improves the barrier capacity against the progression of salts in the most of the cases.

Through the tests can also be pointed out that the type of crystallization below the barrier and above the barrier is not the same in many of the cases. Sometimes the difference is between the type of manifestation of crystallization in the barrier than in the rest of the specimen. This shows that the barrier has an effect on this process.

Although in several of the cases the addition of calcined diatomite improved a more uniform behaviour of the barrier and results of the salts effects, the non calcined diatomite showed better results in some solutions in relation to the previous D. The ongoing research will conclude about the possibility of control these characteristics and use them in a beneficial way.

In the present research it was carried out in the beginning of the PhD a proposal of Rehabilitation /Conservation Manual with the support of Inovadomus and the University of Aveiro in 2011. This Manual is online and represents a first tempt to give information to the owners, technicians, politicians and enterprises for the protection of the regional heritage.

Another step was the preparation and publication of a Maintenance Manual, because the first measure to protect a heritage is to use and to maintain. For this reason, the proposal of the factory Vista Alegre Atlantis to give some information to the owners of the region for the preservation of this type of buildings was welcome during this research. It was prepared a Manual that could be accessible to the population as in terms of language used as in terms of price. It was published by Publindústria Editor in 2014. A few steps that this research want to contribute for the awareness of the cultural value of traditional adobe construction and the need to protect it.

6.4. Future works

For work to follow in the future, this research considers again an integrated approach to conservation, which means developing work with a multidisciplinary conception. For this reason, the following issues will be addressed:

- an architectural assessment of the recent heritage of Modernism and research into specific vulnerabilities and risks;

- the assessment of solutions that can be effective in terms of thermal comfort but also considering as a main purpose compatibility with the authenticity of the building. This approach should include tests of natural ventilation in ancient buildings.

- continuing the work involving the use of diatomite in waterproof barriers, a necessary study that assesses the effects of fire on the walls

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